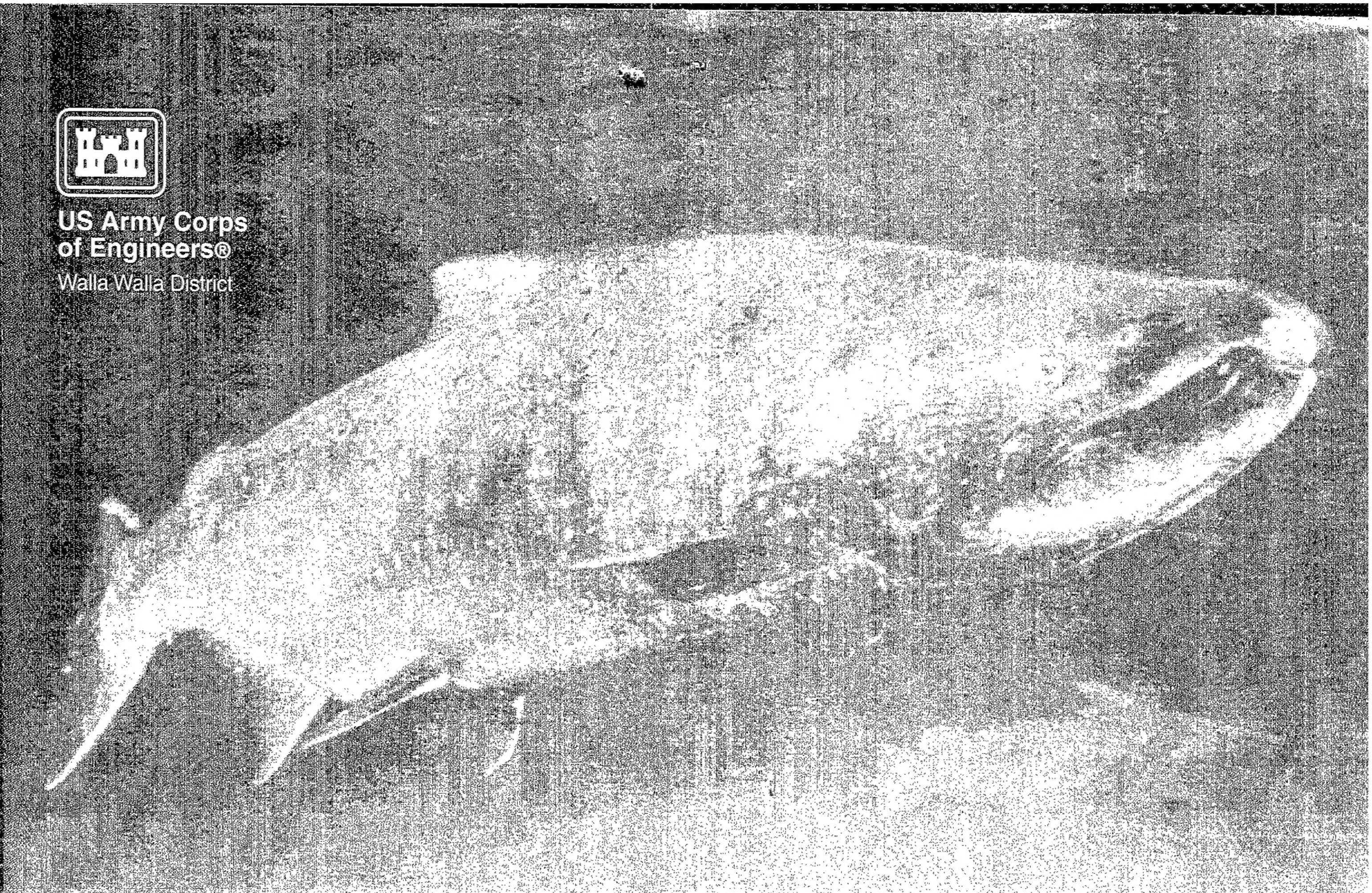


US Army Corps
of Engineers®
Walla Walla District

FINAL

Lower Snake River Juvenile Salmon Migration Feasibility Report/ Environmental Impact Statement

Appendix F
Hydrology/Hydraulics and Sedimentation

Appendix G
Hydroregulations

Appendix H
Fluvial Geomorphology

February
2002

DISTRIBUTION STATEMENT A:
Approved for Public Release -
Distribution Unlimited

01 143

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
February 2002

3. REPORT TYPE AND DATES COVERED
Final

4. TITLE AND SUBTITLE
Lower Snake River Juvenile Salmon Migration Feasibility Report/ Environmental Impact Statement and Appendices F, G, H

5. FUNDING NUMBERS

6. AUTHOR(S)
Corp of Engineers, Walla Walla District

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
US Army Corps of Engineers
Walla Walla District
201 N Third Ave
Walla Walla WA 99362-1876

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
US Army Corps of Engineers
Wash, DC 20314-1000

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
Cooperating Agencies: US Environmental Protection Agency; Bonneville Power Administration; US Bureau of Reclamation

12a. DISTRIBUTION AVAILABILITY STATEMENT
Approval for public release; Distribution is unlimited

20030401 043

13. ABSTRACT *(Maximum 200 words)*
This Final Feasibility Report/Environmental Impact Statement (RE/EIS) and its 21 appendices document the results of a comprehensive analysis of the four dams on the lower Snake River (collectively called the Lower Snake River Project) and their effects on four lower Snake River salmon and steelhead stocks listed for protection under the Endangered Species Act (ESA). The U.S. Army Corps of Engineers (Corps), along with Bonneville Power Agency (BPA), U. S. Environmental Protection Agency (EPA), and U. S. Bureau of Reclamation (BOR) as cooperating agencies, analyzed four alternatives to evaluate the best way to improve juvenile salmon migration through Lower Snake River Project. The Final FR/EIS includes the best available information on the biological effectiveness, engineering components, costs, economic effects, and other environmental effects associated with the four alternatives: Alternative 1-Existing Conditions, Alternative 2-Maximum Transport of Juvenile Salmon, Alternative 3-Major System Improvements (Adaptive Migration), and Alternative 4-Dam Breaching. In the Final FR/EIS, the Corps identifies Alternative 3-Major System Improvements (Adaptive Migration) as the recommended plan (preferred alternative) and explains the process for selecting that alternative.

14. SUBJECT TERMS
Approval for public release; Distribution is unlimited

15. NUMBER OF PAGES

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20 LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

FEASIBILITY STUDY DOCUMENTATION

Document Title

Lower Snake River Juvenile Salmon Migration Feasibility Report/Environmental Impact Statement

*Appendix S, Lower Snake River Maps, is bound separately (out of order) to accommodate a special 11 x 17 format.

The documents listed above, as well as supporting technical reports and other study information, are available on our website at http://www.nww.usace.army.mil/lsr. Copies of these documents are also available for public review at various city, county, and regional libraries.

AQM03-06-1243

STUDY OVERVIEW

Purpose and Need

Between 1991 and 1997, due to declines in abundance, the National Marine Fisheries Service (NMFS) made the following listings of Snake River salmon or steelhead under the Endangered Species Act (ESA) as amended:

- sockeye salmon (listed as endangered in 1991)
- spring/summer chinook salmon (listed as threatened in 1992)
- fall chinook salmon (listed as threatened in 1992)
- steelhead (listed as threatened in 1997).

In 1995, NMFS issued a Biological Opinion on operations of the Federal Columbia River Power System (FCRPS). Additional opinions were issued in 1998 and 2000. The Biological Opinions established measures to halt and reverse the declines of ESA-listed species. This created the need to evaluate the feasibility, design, and engineering work for these measures.

The Corps implemented a study (after NMFS' Biological Opinion in 1995) of alternatives associated with lower Snake River dams and reservoirs. This study was named the Lower Snake River Juvenile Salmon Migration Feasibility Study (Feasibility Study). The specific purpose and need of the Feasibility Study is to evaluate and screen structural alternatives that may increase survival of juvenile anadromous fish through the Lower Snake River Project (which includes the four lowermost dams operated by the Corps on the Snake River—Ice Harbor, Lower Monumental, Little Goose, and Lower Granite Dams) and assist in their recovery.

Development of Alternatives

The Corps' response to the 1995 Biological Opinion and, ultimately, this Feasibility Study, evolved from a System Configuration Study (SCS) initiated in 1991. The SCS was undertaken to evaluate the technical, environmental, and economic effects of potential modifications to the configuration of Federal dams and reservoirs on the Snake and Columbia Rivers to improve survival rates for anadromous salmonids.

The SCS was conducted in two phases. Phase I was completed in June 1995. This phase was a reconnaissance-level assessment of multiple concepts including drawdown, upstream collection, additional reservoir storage, migratory canal, and other alternatives for improving conditions for anadromous salmonid migration.

The Corps completed a Phase II interim report on the Feasibility Study in December 1996. The report evaluated the feasibility of drawdown to natural river levels, spillway crest, and other improvements to existing fish passage facilities.

Based in part on a screening of actions conducted for the Phase I report and the Phase II interim report, the study now focuses on four courses of action:

- Existing Conditions
- Maximum Transport of Juvenile Salmon

- Major System Improvements
- Dam Breaching.

The results of these evaluations are presented in the combined Feasibility Report (FR) and Environmental Impact Statement (EIS). The FR/EIS provides the support for recommendations that will be made regarding decisions on future actions on the Lower Snake River Project for passage of juvenile salmonids. This appendix is a part of the FR/EIS.

Geographic Scope

The geographic area covered by the FR/EIS generally encompasses the 140-mile long lower Snake River reach between Lewiston, Idaho and the Tri-Cities in Washington. The study area does slightly vary by resource area in the FR/EIS because the affected resources have widely varying spatial characteristics throughout the lower Snake River system. For example, socioeconomic effects of a permanent drawdown could be felt throughout the whole Columbia River Basin region with the most effects taking place in the counties of southwest Washington. In contrast, effects on vegetation along the reservoirs would be confined to much smaller areas.

Identification of Alternatives

Since 1995, numerous alternatives have been identified and evaluated. Over time, the alternatives have been assigned numbers and letters that serve as unique identifiers. However, different study groups have sometimes used slightly different numbering or lettering schemes and this has led to some confusion when viewing all the work products prepared during this long period. The primary alternatives that are carried forward in the FR/EIS currently involve the following four major courses of action:

Alternative Name	PATH[1/] Number	Corps Number	FR/EIS Number
Existing Conditions	A-1	A-1	1
Maximum Transport of Juvenile Salmon	A-2	A-2a	2
Major System Improvements	A-2'	A-2d	3
Dam Breaching	A-3	A-3a	4

[1/] Plan for Analyzing and Testing Hypotheses

Summary of Alternatives

The **Existing Conditions Alternative** consists of continuing the fish passage facilities and project operations that were in place or under development at the time this Feasibility Study was initiated. The existing programs and plans underway would continue unless modified through future actions. Project operations include fish hatcheries and Habitat Management Units (HMUs) under the Lower Snake River Fish and Wildlife Compensation Plan (Comp Plan), recreation facilities, power generation, navigation, and irrigation. Adult and juvenile fish passage facilities would continue to operate.

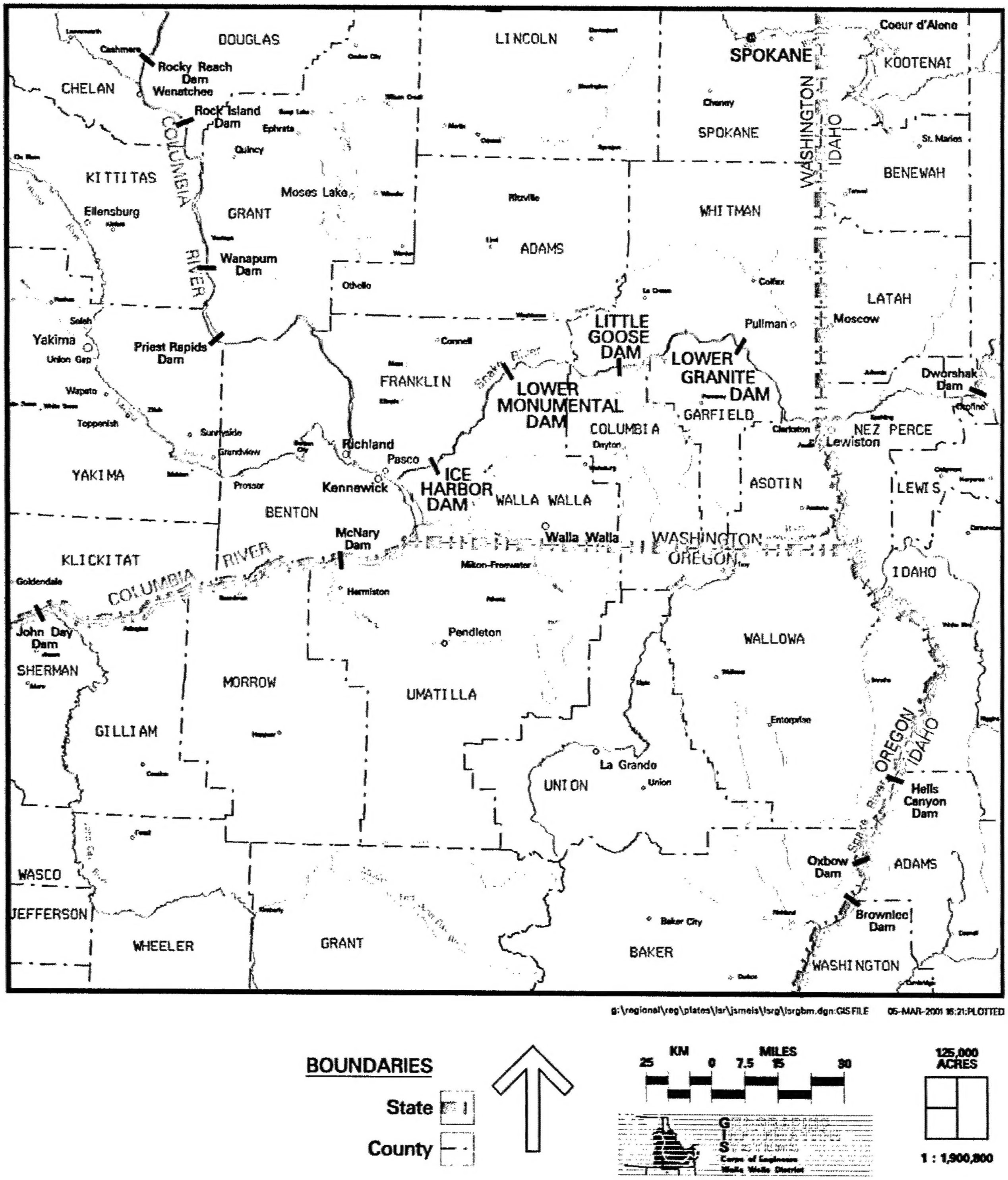
The **Maximum Transport of Juvenile Salmon Alternative** would include all of the existing or planned structural and operational configurations from the Existing Conditions Alternative. However, this alternative assumes that the juvenile fishway systems would be operated to maximize fish transport from Lower Granite, Little Goose, and Lower Monumental and that voluntary spill would not be used to bypass fish through the spillways (except at Ice Harbor). To accommodate this maximization of transport, some measures would be taken to upgrade and improve fish handling facilities.

The **Major System Improvements Alternative** would provide additional improvements to what is considered under the Existing Conditions Alternative. These improvements would be focused on using surface bypass facilities such as surface bypass collectors (SBCs) and removable spillway weirs (RSWs) in conjunction with extended submerged bar screens (ESBSs) and a behavioral guidance structure (BGS). The intent of these facilities would be to provide more effective diversion of juvenile fish away from the turbines. Under this alternative, an adaptive migration strategy would allow flexibility for either in-river migration or collection and transport of juvenile fish downstream in barges and trucks.

The **Dam Breaching Alternative** has been referred to as the "Drawdown Alternative" in many of the study groups since late 1996 and the resulting FR/EIS reports. These two terms essentially refer to the same set of actions. Because the term drawdown can refer to many types of drawdown, the term dam breaching was created to describe the action behind the alternative. The Dam Breaching Alternative would involve significant structural modifications at the four lower Snake River dams, allowing the reservoirs to be drained and resulting in a free-flowing yet controlled river. Dam breaching would involve removing the earthen embankment sections of the four dams and then developing a channel around the powerhouses, spillways, and navigation locks. With dam breaching, the navigation locks would no longer be operational and navigation for large commercial vessels would be eliminated. Some recreation facilities would close while others would be modified and new facilities could be built in the future. The operation and maintenance of fish hatcheries and HMUs would also change, although the extent of change would probably be small and is not known at this time.

Authority

The four Corps dams of the lower Snake River were constructed and are operated and maintained under laws that may be grouped into three categories: 1) laws initially authorizing construction of the project, 2) laws specific to the project passed subsequent to construction, and 3) laws that generally apply to all Corps reservoirs.



LOWER SNAKE RIVER
Juvenile Salmon Migration Feasibility Study

REGIONAL BASE MAP

US Army Corps of Engineers®
Walla Walla District

Final

Lower Snake River Juvenile Salmon Migration Feasibility Report/ Environmental Impact Statement

Appendix F

Hydrology/Hydraulics and Sedimentation

February 2002

US Army Corps
of Engineers®
Walla Walla District

Final

Lower Snake River Juvenile Salmon Migration Feasibility Report/ Environmental Impact Statement

Appendix F
Hydrology/Hydraulics and Sedimentation

Produced by

U.S. Army Corps of Engineers
Walla Walla District

February 2002

H:\WP\1346\Appendices\FEIS\F - Hydrology\CamRdy\App_F.doc

FOREWORD

Appendix F was prepared by the U.S. Army Corps of Engineers (Corps), Walla Walla District. This appendix is one part of the overall effort of the Corps to prepare the Lower Snake River Juvenile Salmon Migration Feasibility Report/Environmental Impact Statement (FR/EIS).

The Corps has reached out to regional stakeholders (Federal agencies, tribes, states, local governmental entities, organizations, and individuals) during the development of the FR/EIS and appendices. This effort resulted in many of these regional stakeholders providing input and comments, and even drafting work products or portions of these documents. This regional input provided the Corps with an insight and perspective not found in previous processes. A great deal of this information was subsequently included in the FR/EIS and appendices; therefore, not all of the opinions and/or findings herein may reflect the official policy or position of the Corps.

This page is intentionally left blank.

CONTENTS

CONTENTS

TABLES

PLATES

CHARTS

ACRONYMS AND ABBREVIATIONS

ASCE	American Society of Civil Engineers
C	Celsius
cfs	cubic feet per second
Corps	U.S. Army Corps of Engineers
F	Fahrenheit
FPM	feet per mile
FR/EIS	Lower Snake River Juvenile Salmon Feasibility Report/ Environmental Impact Statement
FRI-UW	Fisheries Research Institute-University of Washington
HEC	Hydrologic Engineering Center
HM	hectare-meters
m^3/s	cubic meters per second
MCMTR	million cubic meters
MCYD	million cubic yards
mg/l	milligrams per liter
mm	millimeters
MPK	meters per kilometer
NGVD29	National Geodetic Vertical Datum 1929
ppm	parts per million
RKM	river kilometer
RM	River Mile
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
WSP	Water Supply Paper

ENGLISH TO METRIC CONVERSION FACTORS

To Convert From	To	Multiply By
LENGTH CONVERSIONS:		
Inches	Millimeters	25.4
Feet	Meters	0.3048
Miles	Kilometers	1.6093
AREA CONVERSIONS:		
Acres	Hectares	0.4047
Acres	Square meters	4047
Square Miles	Square kilometers	2.590
VOLUME CONVERSIONS:		
Gallons	Cubic meters	0.003785
Cubic yards	Cubic meters	0.7646
Acre-feet	Hectare-meters	0.1234
Acre-feet	Cubic meters	1234
OTHER CONVERSIONS:		
Feet/mile	Meters/kilometer	0.1894
Tons	Kilograms	907.2
Tons/square mile	Kilograms/square kilometer	350.2703
Cubic feet/second	Cubic meters/sec	0.02832
Degrees Fahrenheit	Degrees Celsius	(Deg F –32) x (5/9)

Executive Summary

Approximately 76.5 to 114.7 million cubic meters (100 to 150 million cubic yards) of sediment have been deposited upstream of the four lower Snake River dams since Ice Harbor Dam became operational in the early 1960s. Sediment totaling 0.76 million cubic meters (1 million cubic yards) will cover a section of land (2.59 square kilometers or 1 square mile) to a depth of approximately one-third meter (1 foot). Implementation of Alternative 1 (Existing System), Alternative 2 (Maximum Transport of Juvenile Salmon), or Alternative 3 (Major System Improvements) would have similar long-term results with respect to sedimentation, with Lower Granite Reservoirs continuing to trap the majority of inflowing sediments from the Snake and Clearwater rivers. However, if Alternative 4 (Dam Breaching) is implemented and the four lower Snake River dams are breached, approximately 50 percent (one-half) of the previously deposited materials will be eroded and transported by the Snake River within the first few years following dam breaching. The eroded materials will most likely be redeposited in Lake Wallula between the Snake River and Wallula Gap. Because the McNary Dam backwater pool extends upstream to Ice Harbor Dam, the very coarsest cobble materials could start depositing in the vicinity of Ice Harbor Dam. However, they could later be subject to resuspension and further transport downstream to Lake Wallula by floods that exceed the flows experienced at the time of their original deposition. The coarsest sediments would be deposited first, with the sediment deposits becoming progressively finer as they are transported farther downstream into Lake Wallula. Since these materials could previously be deposited behind the lower Snake River dams, and since flow velocities in Lake Wallula are generally lower than Snake River velocities, most of these sediments probably would be deposited in Lake Wallula rather than being transported downstream of McNary Dam. The remainder of the sediments previously deposited upstream of the lower Snake River dams and not eroded within the first few years of dam breaching would be subject to long-term erosion by wind and precipitation and could eventually also be transported downstream to Lake Wallula by the Snake River.

Between its confluence with the Snake River and Wallula Gap, the Columbia River covers an area approximately 16.1 kilometers (10 miles) long and 3,048 meters (10,000 feet) wide. Based on qualitative information, it appears quite likely that sediments larger than approximately 0.02 millimeter in diameter would deposit within this reach, while those smaller than 0.02 millimeter in diameter would likely pass downstream through the McNary Dam and likely continue to be transported as suspended sediment load downstream to the Columbia River estuary near the Pacific Ocean. The McNary Dam would likely capture all inflowing bed load materials.

The left (east) bank of the Columbia River, between its confluence with the Snake River downstream and its confluence with the Walla Walla River, appears to be susceptible to sediment deposition, based on qualitative analyses. Actual sedimentation patterns and depths are extremely difficult to predict in advance due to the numerous variable factors involved. Future proactive measures to protect water intakes from sedimentation effects might be required along this reach, although site-specific details are extremely difficult to predict in advance.

The lower Snake River downstream of Lewiston, Idaho, annually transports approximately 2.3 to 3.1 million cubic meters (3 to 4 million cubic yards) of new sediments that have been eroded from its drainage basin. If the four lower Snake River dams are breached, this material would be transported by the Snake River downstream to the Columbia River. Since the lower Snake River

dams would no longer be available to capture sediments inflowing annually, all but the finest suspended sediments carried by the Snake River would likely deposit within Lake Wallula. The very fine sediments that do not deposit in Lake Wallula would continue to be transported downstream of McNary Dam with their ultimate destination likely being the Columbia River estuary or the Pacific Ocean. If the four Lower Snake River dams are removed, the estimated cost for a sedimentation monitoring program designed to evaluate erosion and sediment transport during the first 10 years after dam breaching is estimated to be $2,158,680. Plates, tables, and charts presenting information related to lower Snake River facility storage curves, system flood control transfers, water travel times, and refill times are presented in this report.

1. Snake River Basin Description

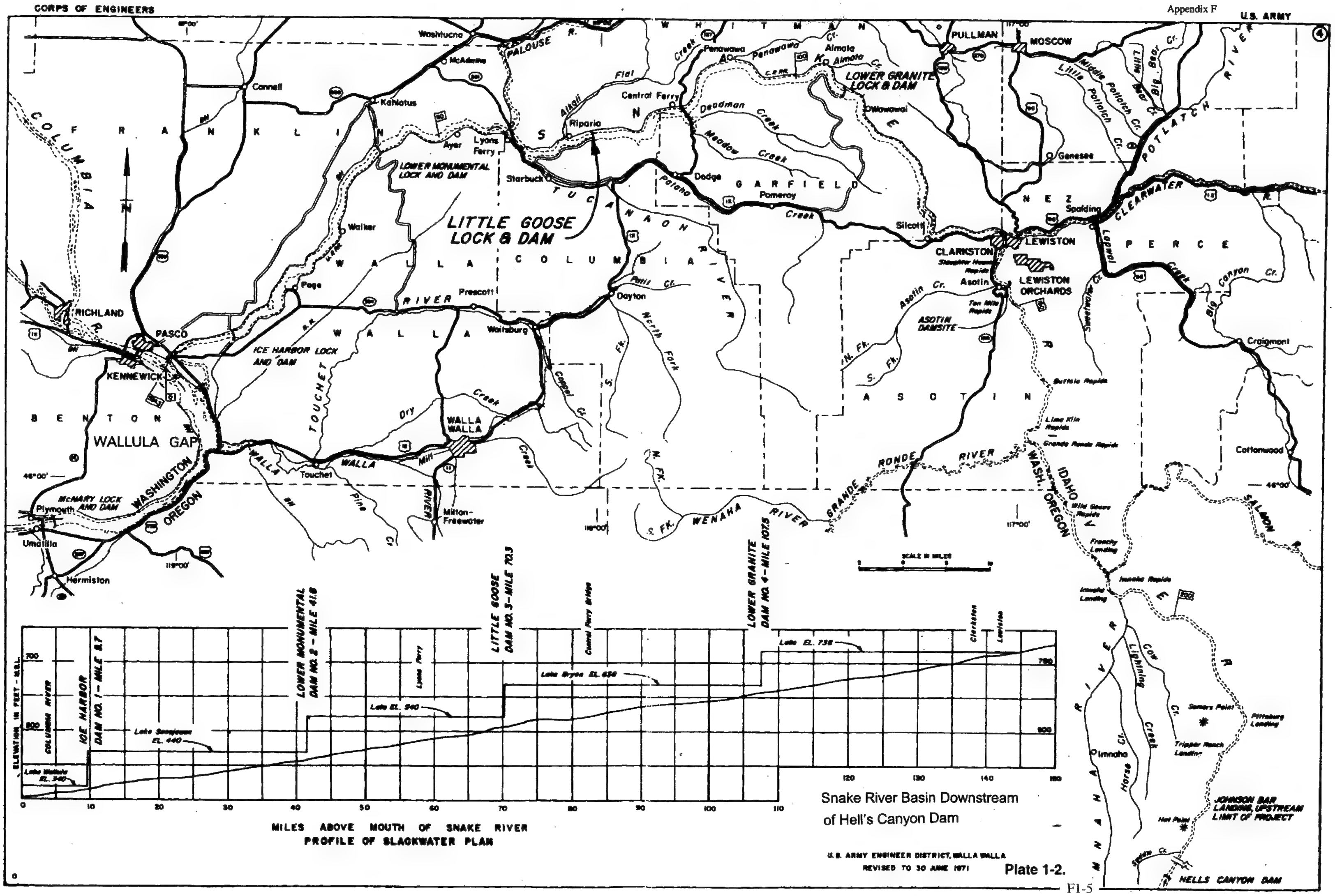
The Snake River Basin has a total drainage area of approximately 281,533 square kilometers (108,700 square miles) upstream of its confluence with the Columbia River near Pasco, Washington. Approximately 5 percent of the Snake River's total drainage area is located downstream of its confluence with the Clearwater River at Lewiston, Idaho, and this region is relatively arid compared to the Snake River's upstream drainage areas. Therefore, only a relatively small amount of runoff occurs along the lower Snake River downstream of the Clearwater River confluence. Runoff is contributed primarily from the Tucannon and Palouse Rivers, which both empty into the Snake River between Lower Monumental Dam and Little Goose Dam. Most of Idaho and lesser amounts of Oregon, Washington, Wyoming, Nevada, and Utah are within the Snake River Basin. The greatest overall dimensions of the basin are approximately 724 kilometers (450 miles) in both the north-south and east-west directions, measured as a straight line distance. Plate 1-1 is a map of the entire Snake River Basin and may be referenced for locations cited in this report. Plate 1-2 is a more detailed map of the lower Snake River Basin downstream of Hells Canyon Dam, and also illustrates portions of the Columbia River Basin upstream of McNary Dam. Table 1-1 is a listing of drainage areas at selected locations within the Snake River Basin as well as United States Geological Survey (USGS) gaging stations at selected sites within the basin downstream of Hells Canyon Dam.

This page is intentionally left blank.

LOWER SNAKE RIVER
Juvenile Salmon Migration Feasibility Study

Plate 1-1.
WALLA WALLA DISTRICT BASIN MAP

This page is intentionally left blank.



Snake River Basin Downstream of Hell's Canyon Dam

Plate 1-2.

Table 1-1. Snake River Basin Drainage Area and Stream Gage Summary

Location	USGS Station Number	Drainage Area (square kilometer/square mile)
Snake River at Hells Canyon Dam	13290450	189,847/73,300
Imnaha River at Imnaha, Oregon	13292000	1,611/622
Imnaha River at Snake River	none	1,813/700 (estimated)
Salmon River at Whitebird, Idaho	13317000	35,094/13,550
Salmon River at Snake River	none	36,519/14,100 (estimated)
Grande Ronde River at Troy, Oregon	13333000	8,482/3,275
Grande Ronde River at Snake River	none	10,541/4,070 (estimated)
Snake River near Anatone, Washington	13334300	240,766/92,960
Snake River at Clearwater River	none	242,165/93,500 (estimated)
North Fork Clearwater River at Dworshak Dam	none	6,320/2,440
Clearwater River at Spalding, Idaho	13342500	24,216/9,350
Clearwater River at Snake River	none	24,968/9,640 (estimated)
Snake River at Lower Granite Dam	none	267,288/103,200 (estimated)
Tucannon River near Starbuck, WA	13344500	1,116/431
Tucannon River at Snake River	none	1,424/550 (estimated)
Palouse River at Hooper, Washington	13351000	6,475/2,500
Palouse River at Snake River	none	6,734/2,600 (estimated)
Snake River at Columbia River	none	281,533/108,700 (estimated)
Columbia River below Priest Rapids Dam	12472800	248,640/96,000
Yakima River at Kiona, Washington	12510500	14,543/5,615
Yakima River at Columbia River	none	15,022/5,800 (estimated)
Columbia River at Snake River	none	266,770/103,000 (estimated)
Walla Walla River near Touchet, WA	14018500	4,292/1,657
Walla Walla River at Columbia River	none	4,662/1,800 (estimated)
Columbia River at McNary Dam	14019200	554,260/214,000

Notes:
1. USGS is acronym for United States Geological Survey
2. One square mile equals 2.590 square kilometers

This page is intentionally left blank

2. Columbia River Basin Description

The Columbia River has a total drainage area of approximately 554,260 square kilometers (214,000 square miles) measured at McNary Dam, which is located at Columbia River kilometer 469.8 (river mile 292), and which is located approximately 51.5 river kilometers (32 river miles) downstream of the Columbia River's confluence with the Snake River. Plate 1-2 shows the location of McNary Dam. The Columbia River's drainage area upstream of the Snake River confluence is approximately 266,770 square kilometers (103,000 square miles). Thus at the confluence of the Snake and Columbia rivers, both rivers have approximately the same drainage area, with the Snake River drainage area being slightly larger than the Columbia River drainage area at this location.

This page is intentionally left blank.

3. Snake River Stream Description

The Snake River is 1,734 kilometers (1,078 miles) long and is the largest tributary of the Columbia River. It originates high in the Yellowstone National Park area of western Wyoming and traverses the southern part of Idaho in a broad arc running from east to west. It then flows almost due north, forming part of the boundary between Idaho, Oregon, and Washington. Near Lewiston, Idaho, it turns abruptly to the west and joins the Columbia River near Pasco, Washington. Total fall of the Snake River from its source near Two Ocean Plateau, Wyoming, to its confluence with the Columbia River is approximately 2,896 meters (9,500 feet), with an average slope of approximately 1.7 meters per kilometer (8.8 feet per mile) over its entire length. Between Lewiston and Pasco, the lower Snake River falls approximately 122 meters (400 feet) vertically in a distance of approximately 225 kilometers (140 miles), with an average slope of approximately 0.54 meters per kilometer (3 feet per mile) along this reach.

This page is intentionally left blank.

4. Existing Snake River Basin Water Resources Projects

The numerous artificial reservoirs and partially controlled lakes in the Snake River Basin have a substantial effect on the flow characteristics of the lower Snake River. Total usable storage in these upstream lakes and reservoirs is approximately 1,184,185 hectare-meters (9,600,000 acre-feet). Dworshak Reservoir has the greatest usable storage capacity with approximately 246,705 hectare-meters (2,000,000 acre-feet). It is followed with respect to usable capacity by American Falls Reservoir with approximately 209,699 hectare-meters (1,700,000 acre-feet), Palisades Reservoir with approximately 148,270 hectare-meters (1,202,000 acre-feet), Brownlee Reservoir with approximately 120,886 hectare-meters (980,000 acre-feet), and the Boise River Reservoir system with approximately 120,145 hectare-meters (974,000 acre-feet) combined storage within the Lucky Peak, Arrowrock, and Anderson Ranch Reservoirs.

This page is intentionally left blank.

5. Snake River Basin Geography and Geology

Several complex systems of mountain ranges, with intervening valleys and plains, lie within the Snake River Basin. Much of the southern part of the basin is included within the Columbia Plateau Province, a semiarid expanse formed by successive flows of basaltic lava. To the north of this plateau is a rugged area of mountain ridges and troughs, with deeply incised stream channels. This mountainous area is included within the Northern Rocky Mountain Province. Overall extremes of elevation are 4,196 meters (13,766 feet) above National Geodetic Vertical Datum 1929 (NGVD29) at Grand Teton Mountain in Wyoming to approximately 91.4 meters (300 feet) above NGVD29 at the Snake River's confluence with the Columbia River. The basin mean elevation is approximately 1,585 meters (5,200 feet) above NGVD29. Fenneman (1931) as well as other geography and geology texts should be consulted for a more in-depth discussion of the Snake River Basin's geography and geology.

The Snake River flows across a major physiographic region of the Pacific Northwest known as the Snake River Plateau and along the southern portion of the Columbia Plateau. The Snake River Plateau extends from southwestern Oregon across southern Idaho and includes parts of Nevada and Utah. The Columbia Plateau extends south from the upper curve of the Columbia River to the Blue Mountains, west to the Cascades, and east above the Snake River, just east of the Washington-Idaho state line. These two regions are comprised mainly of lava flows covered with soil. In areas where the Snake River has cut canyons, the dark basalt rock is a primary surface feature. Many of the soils of the Snake River Plateau are light and highly erodible with low rainfall limiting the ability of vegetative cover to reestablish once removed. This results in heavy sediment loads in the river, especially during the spring runoff season.

This page is intentionally left blank.

6. Snake River Basin Climate

Generally, the climate of the Snake River Basin is transitional between the maritime regimen west of the Cascade Mountain Range and the continental type climate of the northern Great Plains. Both maritime and continental air masses affect the basin, but since it is located in the zone of prevailing westerly flow, the maritime air masses predominate. The Rocky Mountains, located to the north and east, provide some protection against outbreaks of cold arctic air from Canada, but such incursions do occur occasionally in the winter season, particularly over the eastern part of the Snake River Basin. Because of the irregular topography and large differences in elevation and exposure, there are pronounced differences of local climates within the basin.

This page is intentionally left blank.

7. Snake River Basin Air Temperatures

Air temperatures within the Snake River Basin are controlled by elevation and distance from the Pacific Ocean, as well as by individual air masses and the season of the year. An important aspect of basin temperature to the regulation of water resources projects lies in the effect of temperature and solar radiation on snowmelt. The shape, timing, and peak discharge of the spring snowmelt runoff of the lower Snake River are determined to a considerable degree by the sequence of spring season basin temperatures. In addition, temperatures in the region have a pronounced effect on electric power demand and therefore on generation at hydroelectric projects that serve the area.

Normal summer maximum temperatures for most climatological stations are between 26.7 and 32.2 degrees Celsius (C) (80 and 90 degrees Fahrenheit [F]), and normal winter minimums are between -17.8 and -6.7 degrees C (0 and 20 degrees F). Extreme recorded temperatures are -54.4 degrees C (-66 degrees F) at West Yellowstone, Montana, which is located immediately outside the upper Snake River Basin boundary, and 47.8 degrees C (118 degrees F) at Ice Harbor Dam, Washington, and at Orofino, Idaho. Average frost-free periods in agricultural areas vary with location from about 50 to 200 days, and some small high elevation areas experience frost in every month of the year.

This page is intentionally left blank.

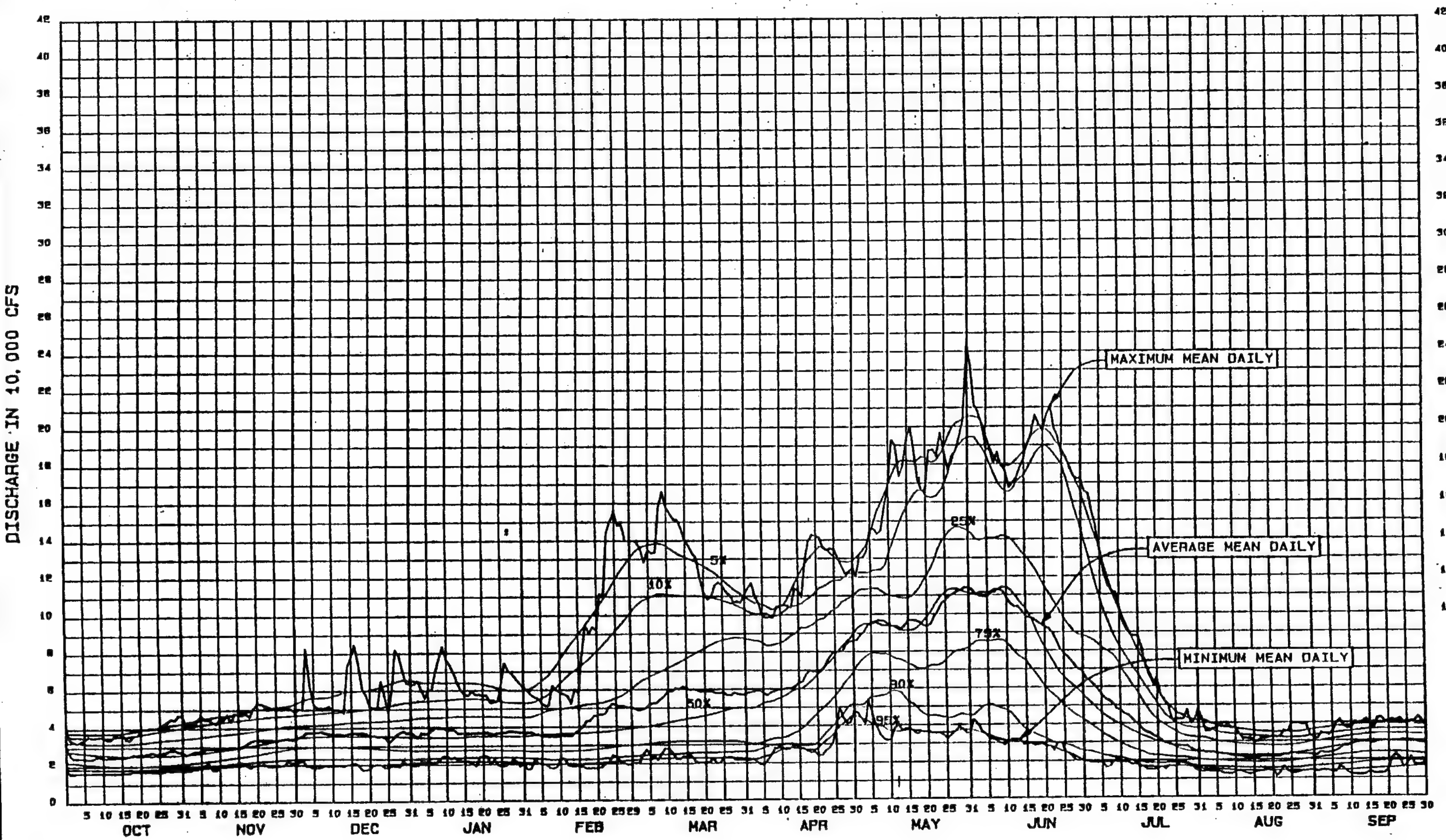
8. Snake River Basin Precipitation

The normal annual precipitation over the Snake River Basin ranges from less than 203 millimeters (8 inches) in the vicinity of Ice Harbor Dam and in portions of the plains of southern Idaho to an estimated maximum of 1,778 millimeters (70 inches) in the Bitterroot Mountains. The normal annual precipitation averaged over the entire basin is estimated to be approximately 508 millimeters (20 inches). Much of the winter precipitation is in the form of snow, a factor of great hydrologic importance. Snow course data are used for forecasting runoff volumes from major basins within the Snake River Basin.

This page is intentionally left blank.

9. Snake River Discharge Characteristics

Plate 9-1 presents the Snake River Summary Hydrographs for inflows into Lower Granite Lake. Plate 9-2 presents the Annual Peak Discharge Frequency Curves for the Snake River at Lower Granite Dam. Inflows into the Snake River between the Clearwater River and the Columbia River are minor when compared to the total Snake River discharge at Lower Granite Lake. Therefore, these summary hydrographs and peak discharge frequency curves may also be considered to be representative of the entire lower Snake River between the Clearwater and Columbia rivers.



NOTES:

1. SUMMARY HYDROGRAPHS PLOTTED FROM CORPS OF ENGINEERS MEAN DAILY INFLOW DATA FOR LOWER GRANITE DAM.
2. PERIOD OF RECORD IS OCT. 1975 THROUGH SEP. 1991
3. DRAINAGE AREA IS 103500 SQUARE MILES.
4. EXCEEDENCE LINES REPRESENT THE PERCENTAGE OF TIME THE FLOW IS EQUALLED OR EXCEEDED ON THAT PARTICULAR DAY.

SNAKE RIVER, WA

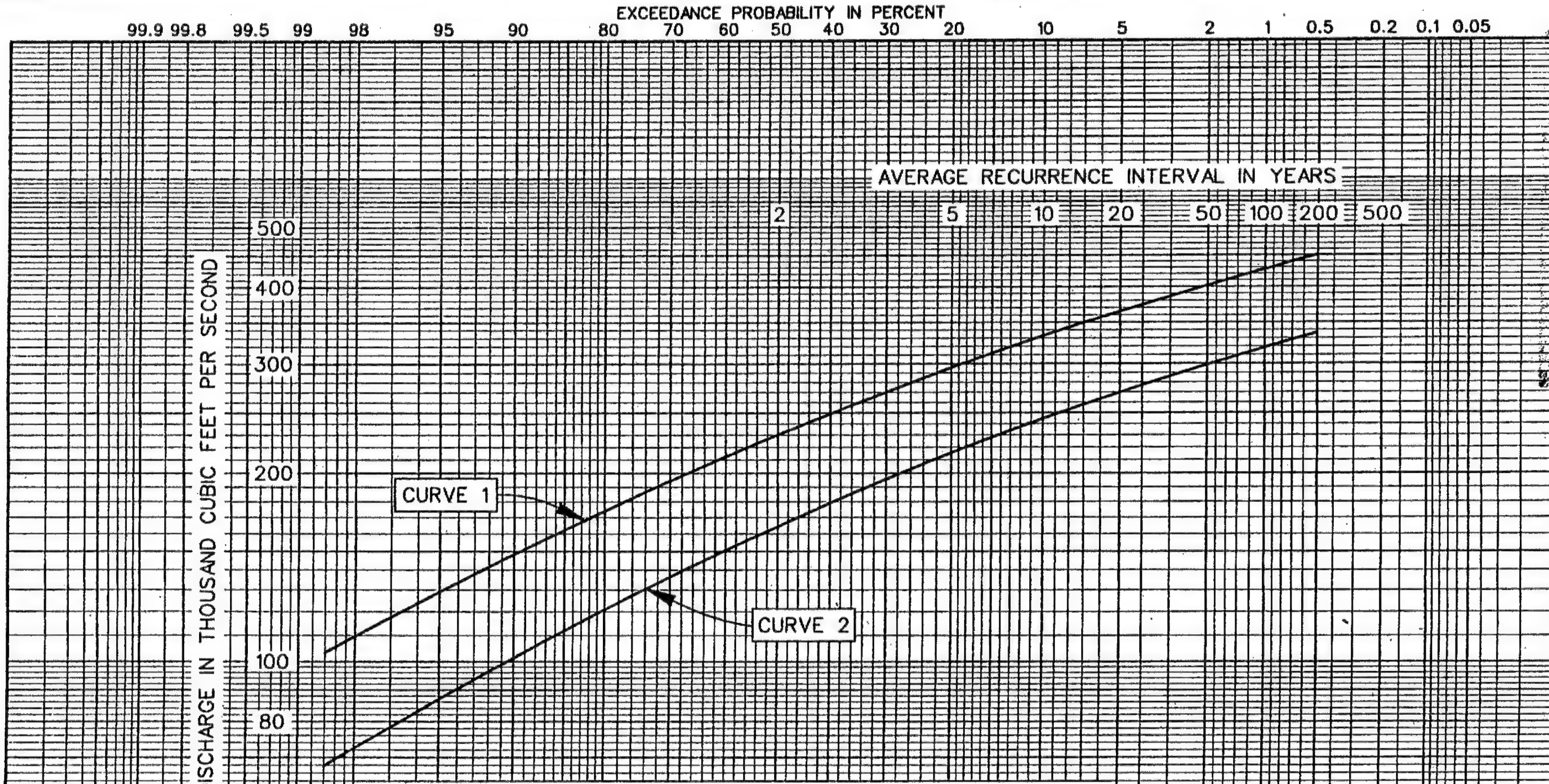
LOWER GRANITE INFLOW

SUMMARY HYDROGRAPHS

U.S. ARMY ENGINEER DISTRICT

WALLA WALLA - HYDROLOGY BRANCH

MAXSON AUGUST 1992



NOTES:

1. Drainage area equals 103,200 square miles.

2. This is a preliminary graph subject to revision.

3. Curve 1 represents natural discharges and is based on the 1894-1975 station record adjusted for irrigation depletions and storage and extended by correlation with the 1858-1975 Columbia River at The Dalles station record. It includes an expected probability adjustment. The station and adopted skew is -0.5. Natural discharges for the 1894-1975 period of record are plotted based on their ranking within the extended record. The median plotting position method was utilized.

4. Curve 2 represents regulated discharges and is based on the 1975 level of storage development and the 1985 level on irrigation depletions. Regulated discharges are from regulation studies for 1894, 1929 through 1958. and in addition the regulated observed discharges for the high runoff years of 1972 and 1974. The plotting positions for the regulated event years are for the natural frequency curve. Curve 2 is a graphical fit of the regulated data.

5. Curves were redrawn from copy of Plate 9-1, Water Control Manual for Lower Granite Lock and Dam, done by NPDEN-WM-HES dated May, 1978.

SNAKE RIVER BASIN
SNAKE RIVER AT LOWER GRANITE DAM

ANNUAL PEAK DISCHARGE FREQUENCY CURVES

U. S. ARMY ENGINEER DISTRICT
WALLA WALLA - HYDROLOGY BRANCH

DESIGNED	DRAWN	DATE
NPD	SCHUSTER	AUGUST 1992

A00182

Plate 9-2.

This page is intentionally left blank.

10. Discussion of Low, Average, and High Flow Years (1994, 1995, 1997, Respectively)

Three flow years experienced during the 1990s may be assumed to generally represent a low flow year, an average flow year, and a high flow year. The year 1994 generally represents a lower than average flow year, 1995 generally represents an average flow year, and 1997 generally represents a higher than average flow year. The following runoff information was obtained from USGS water supply papers (WSP) for the respective time periods. The Clearwater River stream flow information was gathered at the USGS Clearwater River at Spalding gage (USGS number 13342500), and the Snake River stream flow information was gathered at the USGS Snake River near Anatone gage (USGS number 13334300). All USGS discharges are given as mean daily values and are not instantaneous discharges. The average mean daily flow for the Clearwater River at Spalding from March 1 through December 31 is 448 cubic meters (m^3/second) (15,820 cubic feet per second [cfs]), based on 1972 to 1998 data that reflected regulation by Dworshak Reservoir. The maximum unregulated discharge for the Clearwater River is 5,013 m^3/second (177,000 cfs), which occurred on May 29, 1948. The minimum unregulated discharge for the Clearwater River is 14 m^3/second (500 cfs), which occurred on January 9, 1937, and on December 1, 1952. The maximum regulated discharge for the Clearwater River is 3,710 m^3/second (131,000 cfs), which occurred on June 16, 1974. The minimum regulated discharge for the Clearwater River is 38 m^3/second (1,350 cfs), which occurred on October 31, 1971. The average mean daily flow for the Snake River for the period of March 1 through December 31 is 1,044 m^3/second (36,860 cfs) based on 1958 to 1998 data. The maximum period of record discharge for the Snake River at Anatone is 5,522 m^3/second (195,000 cfs), which occurred on June 18, 1974. The minimum Snake River discharge is 170 m^3/second (6,010 cfs), which occurred on September 2, 1958. Thus it can be seen that the annual maximum and annual minimum discharge on both the Snake and Clearwater rivers is generally experienced during the fish passage period from March 1 through December 31.

10.1 Low Flow Year Description (1994)

From March 1 through December 31, 1994, the total runoff volume for the Clearwater River was approximately 829,853 hectare-meters (6,724,900 acre-feet). This equates to an average discharge of approximately 314 m^3/second (11,080 cfs) over this 306-day period, which is 134 m^3/second (4,740 cfs) lower than the long-term average for this period. The peak discharge for the Clearwater River during this period was 1,150 m^3/second (40,600 cfs) on May 16. The minimum discharge for the Clearwater River during this period was 66 m^3/second (2,330 cfs) on September 29.

During this same period in 1994, the total runoff volume for the Snake River was approximately 1,575,423 hectare-meters (12,766,800 acre-feet). This equates to an average discharge of approximately 596 m^3/second (21,030 cfs) over this 306-day period, which is 448 m^3/second (15,830 cfs) lower than the long-term average for this period. The peak discharge for the Snake River during this period was 1,821 m^3/second (64,300 cfs) on May 11. The minimum discharge for the Snake River during this period was 274 m^3/second (9,660 cfs) on August 9.

10.2 Average Flow Year Description (1995)

From March 1 through December 31, 1995, the total runoff volume for the Clearwater River was approximately 1,400,763 hectare-meters (11,351,400 acre-feet). This equates to an average discharge of approximately 530 m^3/second (18,700 cfs) over this 306-day period, which is 82 m^3/second (2,880 cfs) greater than the long-term average for this period. The peak discharge for the Clearwater River during this period was 2,104 m^3/second (74,300 cfs) on December 1. The minimum discharge for the Clearwater River during this period was 122 m^3/second (4,300 cfs) on November 5. The fact that both the minimum and maximum mean daily flows for 1995 occurred within one month of each other illustrates the potential short-term variability of discharge within this basin.

This occurrence appears to be related to climatic circumstances, because the Clearwater River at the Spalding gage site rose in mean daily discharge from 586 m^3/second (20,700 cfs) on November 22 to a peak of 2,104 m^3/second (74,300 cfs) on December 1, then dropped to 453 m^3/second (16,000 cfs) on December 10. Concurrently, the South Fork of the Clearwater River at the Stites, Idaho, gage site (USGS number 13338500) was noted to rise in mean daily discharge from 16 m^3/second (559 cfs) on November 22 to a peak of 114 m^3/second (4,040 cfs) on December 1. The gage then dropped to 35 m^3/second (1,250 cfs) on December 10. Also concurrently, the Clearwater River at the Orofino, Idaho, gage site (USGS number 13340000) rose in mean daily discharge from 269 m^3/second (9,490 cfs) on November 22 to a peak of 2,073 m^3/second (73,200 cfs) on December 1. It then dropped to 394 m^3/second (13,900 cfs) on December 10. The North Fork of the Clearwater River's inflow to Dworshak Reservoir was measured at the Canyon Ranger Station, Idaho, gage site (USGS number 13340600). It rose in mean daily discharge from 126 m^3/second (4,460 cfs) on November 22 to a peak of 969 m^3/second (34,200 cfs) on December 1, then dropped to 189 m^3/second (6,680 cfs) on December 10.

During this same period, the total runoff volume for the Snake River was approximately 3,103,757 hectare-meters (25,152,000 acre-feet). This equates to an average discharge over this 306 day period of approximately 1,173 m^3/second (41,420 cfs), which is 129 m^3/second (4,560 cfs) greater than the long-term average for this period. The peak discharge for the Snake River during this period was 3,342 m^3/second (118,000 cfs) on June 5. The minimum discharge for the Snake River during this period was 422 m^3/second (14,900 cfs) on November 5. This serves to illustrate that maximum and minimum discharges on both the Snake and Clearwater rivers may, but not necessarily always, fall during the same time frame, since during 1995 the Snake River peak discharge occurred in early June and the Clearwater River peak discharge occurred in early December.

10.3 High Flow Year Description (1997)

From March 1 through December 31, 1997, the total runoff volume for the Clearwater River was approximately 1,886,107 hectare-meters (15,284,500 acre-feet). This equates to an average discharge of approximately 713 m^3/second (25,180 cfs) over this 306-day period, which is 265 m^3/second (9,360 cfs) greater than the long-term average for this period. The peak discharge for the Clearwater River during this period was 2,305 m^3/second (81,400 cfs) on May 17. The minimum discharge for the Clearwater during this period was 98 m^3/second (3,460 cfs) on September 10.

During this same period, the total runoff volume for the Snake River was approximately 4,230,152 hectare-meters (34,280,000 acre-feet). This equates to an average discharge of approximately 1,600 m^3/second (56,480 cfs) over this 306 day period, which is 556 m^3/second (19,620 cfs) greater than the long-term average for this period. The peak discharge for the Snake River during this period was 4,305 m^3/second (152,000 cfs) on May 11. The minimum discharge for the Snake River during this period was 487 m^3/second (17,200 cfs) on December 6.

This page is intentionally left blank.

11. Early Snake and Columbia River Basin Explorations That Describe Pre-Project Basin Conditions

Among the earliest scientific explorations in eastern Washington for which results have been published were those of Lieutenant Thomas W. Symons, who explored the Columbia River from the Colville Valley downstream to Ainsworth, located near the mouth of the Snake River. His exploration was made in the fall of 1881. His work is documented in "Report of an Examination of the Upper Columbia River and the Territory in its Vicinity," Forty Seventh Congress, 1st Session, Document No. 186, dated 1882 (Symons, 1882). Lieutenant Symons states on page 2 that his investigations were made "to determine its navigability and the advisability of putting steamships on it." His work also describes lands and explorations that were previously made and documented by Governor I.I. Stevens in his Pacific Railroad reports. In addition, Lieutenant Symons includes observations in his report made by Captain George B. McClellan in 1853 that were in turn documented by Governor Stevens in his railroad reports. Lieutenant Symons describes (p. 50) the Ainsworth area at the mouth of the Snake River as "a bleak, dreary waste in which for many miles around sage brush and sand predominate. Ainsworth is one of the most uncomfortable, abominable places in America to live in. You scan the horizon in vain for a tree or anything resembling one. The heat through the summer is excessive and high winds prevail and blow the sands about and into everything. By the glare of the sun and the flying sands one's eyes are in a continual state of winking, blinking, and torment."

Professor Israel C. Russell accomplished the most extensive and important early investigations of the Columbia Plains. The publications "Geologic Reconnaissance in Central Washington," USGS Bulletin No. 108 (1893) (USGS, 1893); "Reconnaissance in Southeastern Washington," USGS Water Supply and Irrigation Paper No. 4, (1897) (USGS, 1897) and "Geology and Water Resources of Nez Perce County, Idaho, Parts I and II," USGS Water Supply and Irrigation Papers No. 53 and No. 54 (USGS, 1901a; USGS, 1901b) document his investigations. These three expeditions were all conducted "for the purpose of ascertaining how far the geological structure of the arid portions of central Washington and Idaho favored the hope of obtaining artesian water for irrigation." Plate 11-1 is a picture of the Snake River canyon upstream of Lewiston, Idaho, taken by Professor Russell. Plate 11-2 is a picture of the Yakima River canyon south of Ellensburg, also taken by Professor Russell.

In the fall of 1902, Frank C. Calkins made an examination of the water resources of a portion of east-central Washington. The area he investigated extended from Ritzville west to Yakima, and from Pasco north to Ephrata. He described the climate at that time as being "arid" and a large portion of the district investigated was "without surface streams available for the uses of mankind" (USGS, 1905, p. 11). He also stated that "surface wells capable of supplying perennially even modest requirements of domestic use can be sunk only in places where conditions are locally favorable" (USGS, 1905, p. 11).

Canyon of Snake River, Looking North, Approximately 20 miles South of Lewiston, Idaho

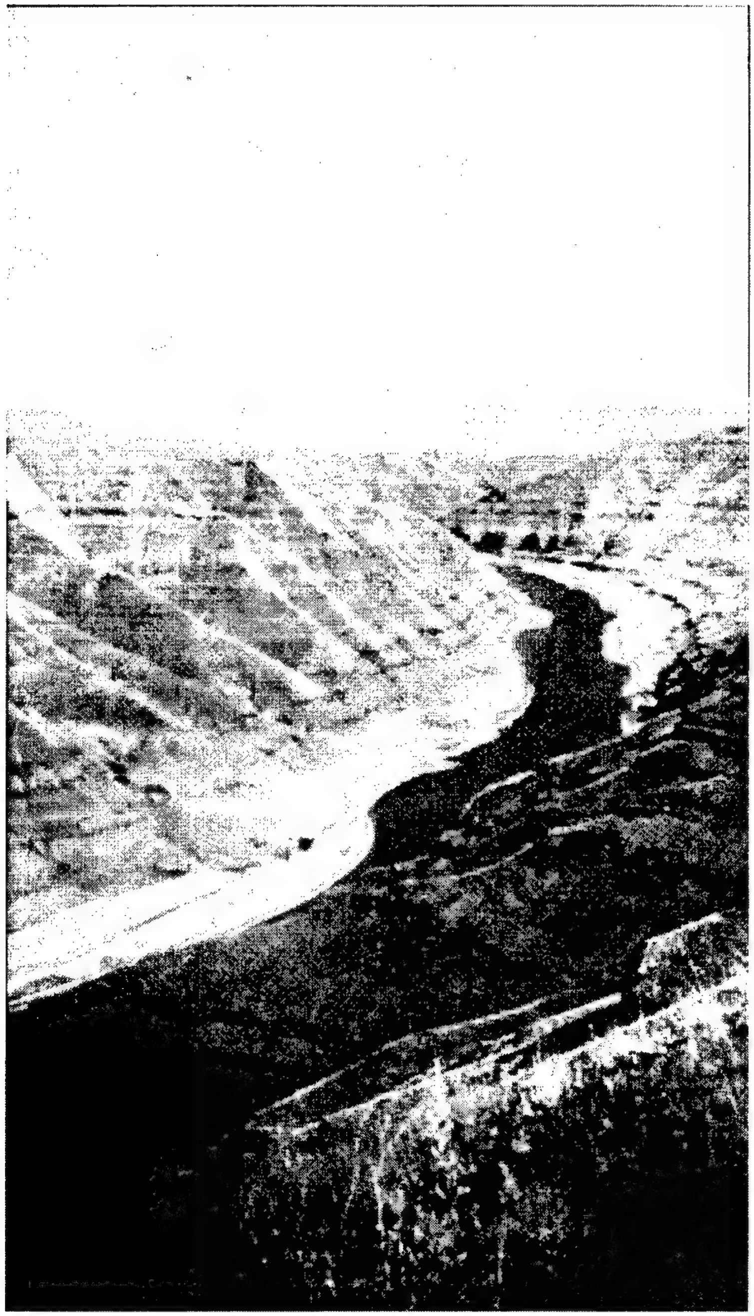


Photo Source: Plate XIII of U.S. Geological Survey Professional Paper 27, by Waldemar Lindgren, 1904, Photo by I.C. Russell.

Plate 11-1. Snake River Upstream of Lewiston, Idaho

Yakima River Canyon, Looking Northwest

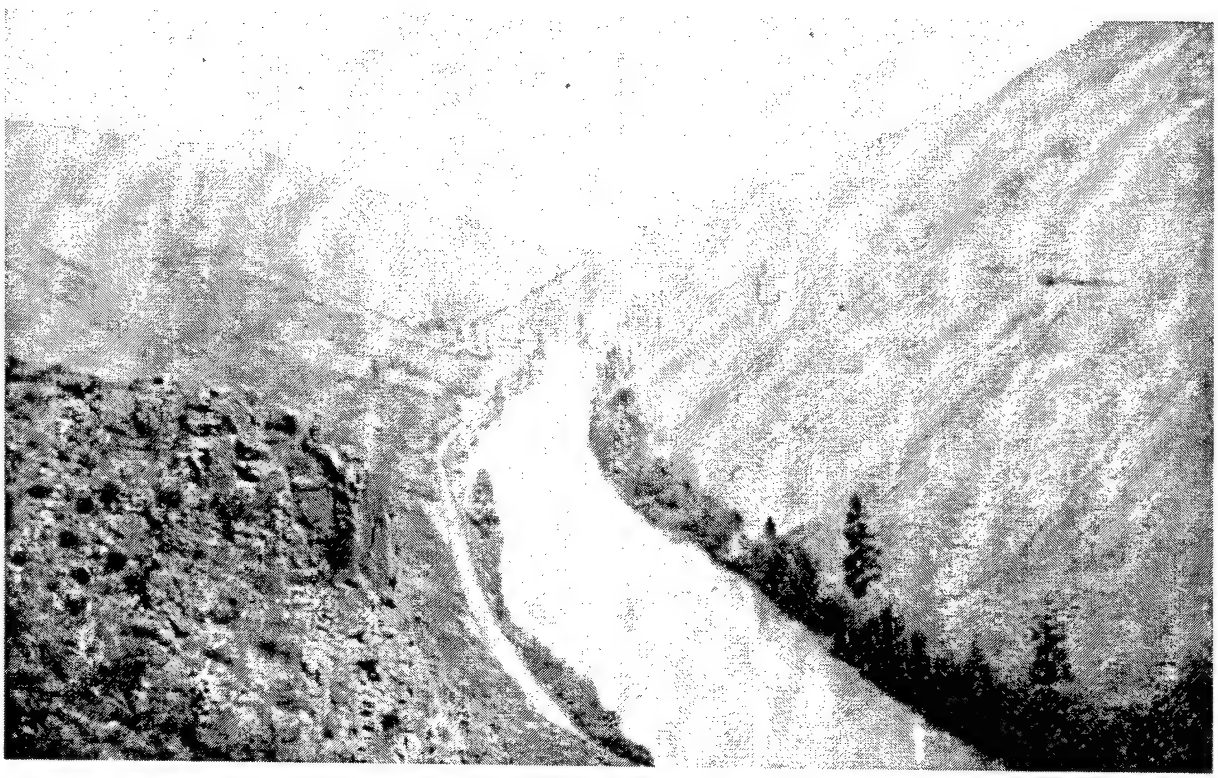


Photo Source: Plate VII of U.S. Geological Survey Bulletin 108, Photo by I.C. Russell.

Plate 11-2. Yakima River Canyon South of Ellensburg, Washington

In 1909, the USGS and the State Board of Health of Washington began a "cooperative study of the quality of the surface waters of the State of Washington, including their seasonal variation in composition and in physical characteristics, and the pollution to which they are subject" (USGS, 1914). Prior to this time, no systematic study of the quality of the surface waters of Washington had been made, although miscellaneous analyses of water from a few lakes and rivers had been published in periodicals or in special reports to municipalities. Analyses of serial samples of water from the Salmon and Palouse rivers were made by the U.S. Reclamation Service in 1905 (USGS, 1914). Samples of water were collected from the Snake River at the Northern Pacific Railway bridge near Burbank, Washington, from March 13, 1910, through January 31, 1911. The quality of the water was subject to considerable variation according to discharge. In Water Supply Paper 339 (USGS, 1914), pages 73-74, it is noted that "the water of the Snake River at Burbank is usually turbid and should be clarified before being used for drinking or manufacturing."

12. Pre-Project Water Temperatures

Prior to the construction of the four lower Snake River facilities, only sporadic water temperature information was gathered on the lower Snake River. Periodic water temperature data was collected on the Snake River near Clarkston, downstream of the Clearwater River at Clarkston, upstream of the Clearwater River confluence, and near Anatone. During Water Years 1952-1956, daily water temperatures were recorded on both the Snake River near Clarkston, at a location downstream of the Snake-Clearwater confluence during Water Years 1952-1955 and at a location near Central Ferry for Water Year 1956, and on the Columbia River at Maryhill Ferry near Rufus, Oregon. This information is recorded in USGS 1957, 1958, 1959a, 1959b, and 1960. In Water Year 1969, four temperature values were published for the Snake River upstream of the Clearwater and ranged from 4 degrees C (39.2 degrees F) on February 24, 1969; to 22 degrees C (71.6 degrees F) on August 10, 1969 (USGS, 1969). From October 1970 through September 1972, eleven temperature values were published, ranging from 1.8 degrees C (35.2 degrees F) on January 13, 1972; to 21.0 degrees C (69.8 degrees F) on August 31, 1971 (USGS, 1972). During Water Years 1958 through 1976, daily water temperatures were recorded for the Columbia River at the Dalles (USGS Station Number 14105700) and were obtained electronically from the Portland office of the USGS. Table 12-1 summarizes the Columbia River water temperature information gathered from Water Years 1958 through 1976, as well as that data gathered on the Snake and Columbia Rivers for Water Years 1952-1956. USGS, 1964a; USGS, 1968; and USGS, 1996, also present water temperature information gathered on the Snake and Columbia rivers and may be consulted for a more in-depth presentation and discussion of water temperatures, under both pre-project and post-project conditions.

Table 12-1. Snake and Columbia River Water Temperatures

Temperature	Snake River		Columbia River		Columbia River	
Range (Deg F)	# of Obs	% of Total	# of Obs	% of Total	# of Obs	% of Total
	(YRS 1952-1956)		(YRS 1952-1956)		(YRS 1958-1976)	
32.00 – 35.00	76	4.16	40	2.19	27	0.50
35.01 – 40.00	331	18.12	194	10.62	452	8.35
40.01 – 45.00	234	12.81	295	16.15	1144	21.13
45.01 – 50.00	240	13.13	244	13.35	841	15.53
50.01 – 55.00	247	13.52	257	14.07	571	10.54
55.01 – 60.00	245	13.41	273	14.94	748	13.81
60.01 – 65.00	150	8.21	260	14.23	846	15.62
65.01 – 70.00	204	11.16	205	11.22	698	12.89
70.01 – 75.00	83	4.54	49	2.68	68	1.26
75.01 – 80.00	17	0.93	10	0.55	18	0.33
80.01 – 85.00	0	0.00	0	0.00	2	0.04
85.01 – 90.00	0	0.00	0	0.00	0	0.00
Totals:	**1827**	**100.00**	**1827**	**100.00**	**5415**	**100.00**

Notes:

1. Source of Snake and Columbia river temperature data for Water Year 1952 was United States Geological Survey (USGS) Water Supply Paper (WSP) 1253. For Water Year 1953 data source was USGS WSP 1293. For Water Year 1954 data source was USGS WSP 1353. For Water Year 1955 data source was USGS WSP 1403. For Water Year 1956 data source was WSP 1453. Data used were for USGS gaging station names "Snake River near Clarkston, Washington;" and "Columbia River at Mary Hill Ferry near Rufus, Oregon."
2. Source of Columbia River temperature data for Water Years 1958-1976 was digital data provided by USGS Water Resources Division office in Portland, Oregon. Data used were for USGS gaging station named "Columbia River at The Dalles, Oregon;" USGS Station Number 14105700.
3. All missing pieces of data in the original data sets were developed through linear interpolation between known data points contained in the respective data sets.
4. To convert temperatures from degrees Fahrenheit to degrees Celsius, use this formula: Deg C = (Deg F – 32.0) x (5.0/9.0)

13. Pre-Project Natural Water Surface Level Fluctuations

Prior to the construction of the four lower Snake River facilities, water levels in the lower Snake River were uncontrolled and free to fluctuate as the river's discharge varied throughout the year. At the Riparia gaging site, located approximately at Snake River kilometer 107.8 (river mile 67), the difference between the highest and lowest known river stages is approximately 7.6 meters (25 feet), measured vertically. For the Snake River gaging site near Clarkston, this water surface elevation difference is greater than 9.1 meters (30 feet), measured vertically. Professor Israel Russell stated in 1897 that "when the snow is melting on the mountains of Idaho and Wyoming the Snake River rises from 6.1 to 9.1 meters (20 to 30 feet) above its summer stage, and becomes a wild, rushing flood of muddy water" (USGS, 1897, p. 20). Plate 13-1, a picture taken by Professor Russell, shows an irrigation water wheel on the Salmon River. By noting the height of gravel and cobble deposits on the river's banks, one can see from this picture the magnitude of the annual water level fluctuation on the Salmon River. Similar activity of differing magnitude can be expected on the lower Snake River. Thus the riparian zone in the vicinity of the Snake River subject to annual erosion effects due to natural water level fluctuations is on the order of 7.6 to 9.1 meters (25 to 30 feet), measured vertically. Depending on ground surface slopes at any given location, this may translate into much greater distances when measured along the ground surface at the location of interest.

Since 1897, reservoir projects (flood control and/or irrigation) constructed on the river system above the four Lower Snake River Projects have significantly reduced flood peaks on the Snake River. The following tabulation summarizes flow peak data that were shown on the frequency curves (data period 1894 to 1975) on page F9-3.

Percent Chance Flood	Unregulated m3/second (cfs)	Regulated m3/second (cfs)
50	6,542 (231,000)	4,616 (163,000)
10	9,458 (334,000)	6,910 (244,000)
2	11,412 (403,000)	8,496 (300,000)
1	12,064 (426,000)	9,034 (319,000)

The HEC-2 computer program was used to evaluate general water surface profile differences between the unregulated and regulated flood peaks on the lower Snake River if the Lower Snake River Projects were to be breached. For the 50 percent chance peak, there is an approximate water surface profile reduction difference of 1.52 meters (5 feet) between the 231,000 cfs unregulated peak and the 163,000 cfs regulated peak. For the 1 percent chance peak, there is an approximate water surface profile reduction difference of 2.44 meters (8 feet) between the 426,000 cfs unregulated peak and the 319,000 cfs regulated peak.

Irrigation Water Wheel, Salmon River

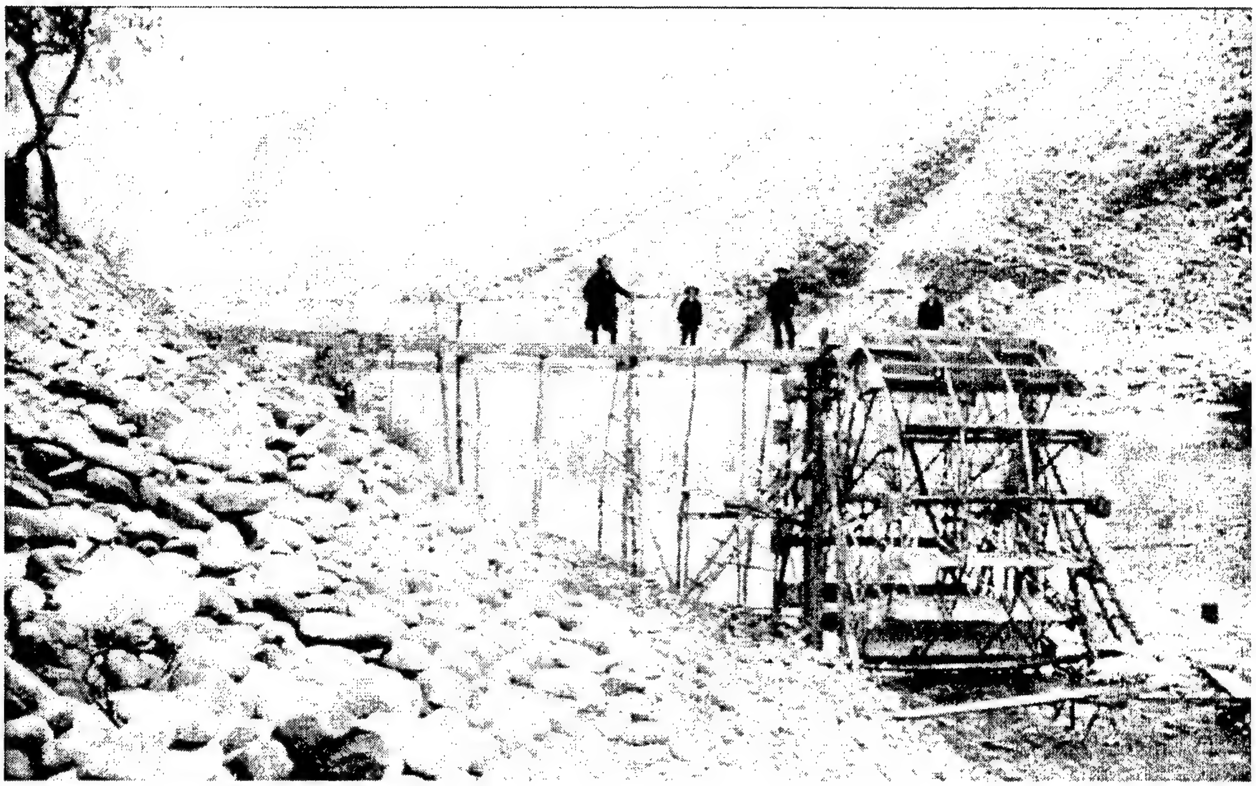


Photo Source: Plate V of U.S. Geological Survey Water Paper 4, Photo by I.C. Russell.

Plate 13-1. Irrigation Water Wheel on Salmon River

14. Generalized Description of Snake River Fish Passage

The adult anadromous fish passage period on the Snake River extends from approximately March 1 through December 31, and the juvenile anadromous fish passage period extends from approximately March 25 through December 15. Potential flow conditions expected during these fish passage periods may be obtained from Plate 9-1, which shows Snake River Summary Hydrographs for the inflow to Lower Granite Reservoir. As can be seen from Plate 9-1, both the annual peak discharge and the annual minimum discharge generally occur during the fish passage period, although exceptions may occur within any given year. Since inflows between Lower Granite and the Columbia River's confluence with the Snake River are relatively minor as compared to the Snake River's total discharge, the Summary Hydrographs shown on Plate 9-1 may also be assumed to apply for the entire Snake River reach downstream of its confluence with the Clearwater River at Lewiston, Idaho.

This page is intentionally left blank.

15. Effects of Turbidity on Fish

Turbidity and fine sediments have long been recognized as affecting aquatic life, with much research activity on a world-wide scale having been devoted to answering questions related to these effects. Both positive and negative effects have been noted, such as reduced predation due to turbidity and decreased fish production due to fine sediment deposition in salmon spawning and rearing areas. Numerous papers have been published on the relationship of turbidity, sediment, and aquatic life; a short, non-inclusive list of references with a brief discussion of each is given here for further study as desired.

"The Direct Effect of Turbidity on Fishes," by I. Eugene Wallen, in The Bulletin of Oklahoma Agricultural and Mechanical College, Stillwater, Oklahoma; Arts and Sciences Studies, Biological Series Number 2, Volume 48, January 1951. This publication describes a test of 380 fish within 16 species to determine the direct effect of montmorillonite clay turbidity on them. These tests indicated that observational behavioral reactions that appeared as a turbidity effect did not develop until concentrations of turbidity neared 20,000 parts per million (ppm). In one species, reactions did not appear until turbidities reached 100,000 ppm. It was also noted that most individuals of all species endured exposures to more than 100,000 ppm of turbidity for a week or longer, but the same fish died at turbidities of 175,000 to 225,000 ppm.

"Turbidity Reduces Predation on Migrating Juvenile Pacific Salmon," by Robert S. Gregory and Colin D. Levings, in Transactions of the American Fisheries Society 127:275-285, 1998. These two authors field-tested the hypothesis that predation by piscivorous fish is reduced in turbid as compared with clear water. Work was done on the Harrison River in Canada (turbidity normally less than 1 nephelometric turbidity unit) and the naturally turbid Fraser River in Canada (turbidity normally ranges from 27 to 108 nephelometric turbidity units).

"The Influence of Turbidity on Juvenile Marine Fishes in Estuaries, Field Studies at Lake St. Lucia on the Southeastern Coast of Africa," by D.P. Cyrus and S.J.M. Blaber, in Journal of Experimental Marine Biology, Volume 109, pages 53-70, 1987, Elsevier Science Publishers. This publication documents a 3.5-year long study, conducted during the early 1980s in Africa, to investigate the relationships between water turbidity and estuarine fish distribution.

"Summer and Winter Habitat Selection by Juvenile Chinook Salmon in a Highly Sedimented Idaho Stream," by T.W. Hillman and J.S. Griffith, in Transactions of the American Fisheries Society 116:185-195, 1987. These two authors assessed the Red River in Idaho, a stream heavily embedded with fine sediment. Their work was accomplished during 1985-1986.

"Recovery of Game Fish Populations Impacted by the May 18, 1980, Eruption of Mount Saint Helens," by Bruce A. Crawford, Fishery Management Report 85-98, Washington Department of Game, May 1986. This report addresses the effect of the eruption on the gamefish fisheries in the lakes in the Mount Saint Helens National Volcanic Monument and the adjacent lakes located within Cowlitz, Lewis, and Skamania counties. The data and observations were collected from May 1980 to May 1986.

"Effects of Mount Saint Helens Eruption on Salmon Populations and Habitat in the Toutle River," by Douglas J. Martin, Lawrence J. Wasserman, Robert P. Jones, and Ernest O. Salo, a Technical Completion Report for the U.S. Department of the Interior, Bureau of Reclamation, October 26,

1984, FRI-UW-8412. This report states that "high concentrations of suspended sediment caused many adult spawners to avoid the Toutle River in 1980 and 1981, and instead return to the Upper Cowlitz River and Kalama River. Adult salmon and steelhead that returned to the Toutle River were observed spawning in most tributaries formerly utilized before the eruption. Adult salmon spawned in unstable volcanic substrates with average concentrations of fine particles (less than 0.850 mm in diameter) ranging from 11.2 percent to 36.0 percent in 1981 and from 11.2 percent to 33.5 percent in 1982." The report also states that "sediment problems and channel instability on the debris avalanche are expected to diminish in 30 to 35 years" and that "smolt survival for the future is optimistic if suspended sediment levels are lower than 5,000 milligrams per liter (mg/l) during the spring outmigration period."

"Habitat Utilization by Juvenile Pacific Salmon if the Glacial Taku River, Southeast Alaska," by Michael L. Murphy, Jonathan Heifetz, John F. Thedinga, Scott W. Johnson, and K.V. Koski, in Canadian Journal of Fish and Aquatic Science, Volume 46, 1989. This study was conducted to determine patterns of habitat use by juvenile salmon in summer in the lower Taku River, a river which is turbid with glacial silt most of the year. The river flow is low (less than 100 m^3/second [3,531 cfs]) in winter and high (greater than 700 m^3/second [24,717 cfs]) during snowmelt in June. Turbidities were noted to range from 0 to 600 Jackson Turbidity Units.

"Effects of Chronic Turbidity on Density and Growth of Steelheads and Coho Salmon," by John W. Sigler, T.C. Bjornn, and Fred H Everest, in Transactions of the American Fisheries Society 113:142-150, 1984. This report states that "yearling and older salmonids can survive high concentrations of suspended sediment for considerable periods, and acute lethal effects generally occur only if concentrations exceed 20,000 mg/l, but little is known about the effects of turbidity on newly emerged young."

"Effects of Suspended Sediments on Aquatic Ecosystems," by C.P. Newcombe and D.D. MacDonald, in North American Journal of Fisheries Management 11:72-82, 1991. In the preparation of this report, more than 70 papers on the effects of inorganic suspended sediments on freshwater and marine fish and other organisms were reviewed to compile a database on such effects. This report states that "despite considerable research, there is little agreement on environmental effects of suspended sediment as a function of concentration and duration of exposure." The report also states that "regression analysis indicates that concentration alone is a relatively poor indicator of suspended sediment effects but the product of sediment concentration (in mg/l) and duration of exposure (in hours) is a better indicator of effects."

"Channel Suspended Sediment and Fisheries: A Synthesis for Quantitative Assessment of Risk and Impact," by Charles P. Newcombe and Jorger O.T. Jensen, in North American Journal of Fisheries Management 16:693-719, 1996. This report presents the results of a meta-analysis of 80 published reports on fish responses to suspended sediment in streams and gives six empirical equations that relate biological response to duration of exposure and suspended sediment concentration. The six equations address various taxonomic groups of lotic, lentic, and estuarine fishes, life stages of species within those groups, and particle sizes of suspended sediments.

All of the above references also include numerous other references within them, which should provide a comprehensive background of turbidity and sediment effects on fisheries.

16. Snake River Basin Sedimentation

The four lower Snake River facilities, as well as other dam and reservoir projects within the Snake River Basin, impound the majority of sediments transported into them by tributary streams. The major storage projects located immediately upstream of Lower Granite Dam are Dworshak Dam on the North Fork of the Clearwater River and Hells Canyon Dam on the main stem of the Snake River. At present, the Lower Granite facility impounds the majority of sediments that are contributed to the Snake River and Clearwater River from upstream portions of the Snake River Basin, which are not tributary to either the Dworshak or Hells Canyon facilities. This includes sediment inflows from the Lochsa River, the South Fork of the Clearwater River, and the Potlatch River, which are tributaries to the Clearwater River, and the Imnaha River, the Salmon River, and the Grande Ronde River, which are tributaries to the Snake River downstream of Hells Canyon Dam. Two major tributaries to the Snake River that enter the Snake River between Lower Granite Dam and the confluence of the Snake River with the Columbia River are the Tucannon River and the Palouse River, which are both tributaries to the Lower Monumental reservoir.

At present on the Columbia River, Priest Rapids Dam, which is the next upstream dam from the Snake-Columbia River confluence, as well as other upstream storage projects, impounds the majority of the sediments presently being transported. In addition to the Snake River, the Yakima River and the Walla Walla River are the two major tributaries to the McNary Dam reservoir (Lake Wallula).

Professor Russell presents an outline sketch of the geological history of Southeastern Washington on pages 88-92 of USGS, 1897. He discusses "reasons for believing that the canyon of the Snake River was excavated to its present depth before the time in the earth's history known as the Glacial Epoch." He states that "a great gravel terrace in the canyon of the Snake River and similar terraces in the canyons of the Columbia and Spokane Rivers show that after they were worn to their present depth they were filled to a height of 91.4 to 121.9 meters (300 to 400 feet)." He also states that "this filling is attributed to the overloading of the streams with debris furnished by glaciers and by swollen mountain streams. The cause of this change was climatic." These observations illustrate the types and magnitudes of sedimentation activity potentially previously experienced along the Snake River over Geologic Time and provide a frame of reference for comparison to potential sedimentation effects that may occur if the lower Snake dams are breached.

This page is intentionally left blank.

17. Snake River Basin Soil Characteristics

Soil characteristics within the Snake River Basin vary considerably by geographic location, making it extremely difficult to apply site-specific information basin wide. For this reason, several of the Snake River's subbasins having published information available will be briefly discussed. Paul E. Packer states in his paper "Status of Research on Watershed Protection Requirements for Granitic Mountain Soils in Southwestern Idaho" (Renard et al., 1997), that "the mountain lands that constitute the upper drainage basins of the Boise, Payette, and Salmon Rivers in south-central Idaho have long presented a difficult watershed management problem." The soil in these basins is generally highly erodible, loose granitic soil, which is highly vulnerable to displacement by raindrop impact and to erosion by overland flow, particularly during high intensity rainstorms. F.G. Renner (1936), in his report "Conditions Influencing Erosion on the Boise Watershed," noted the following relationships:

- Erosion was found to vary directly with the degree to which the plant cover had been depleted and the soil surface disturbed.
- Erosion was found to vary directly with the steepness of slope, increasing up to about 35 percent gradient. On steeper slopes, other factors interfered with the evaluation of this relationship.

It is expected that these relationships may also apply to the Salmon River watershed.

In direct contrast to the coarse granitic soils of the Salmon, Payette, and Boise River basins, much of the central Palouse region in Idaho and Washington is covered chiefly by thick loess deposits that are highly erodible. Loess is a fine-grained windblown deposit of late Pliocene, Pleistocene, and Holocene age and is the most important source of sediment in the Palouse River Basin. One factor responsible for the mechanical shaping of the loess hills, besides normal surface runoff and wind action, is the buildup of large banks of snow on the north and east faces of the hills. As these snowbanks melt, excess runoff causes deeper erosion of the soil on the north and east slopes. This is especially true in the Colfax-Pullman-Moscow area. In the easternmost part of the Palouse River Basin, local relief is high, the loess cover is thin, and precipitation is relatively heavy. In the westernmost part of the Palouse River Basin are scablands that lack an integrated drainage system and have little local relief. Lakes are numerous and signify the lack of integrated drainage. Interchannel areas in the scabland are locally characterized by remnant mantles of loess.

Sediment transport in the Palouse River Basin is highly dependent on climatic activity. During a four year study period extending from July 1961 through June 1965, 81 percent of the total 4 year suspended sediment load occurred during the storm periods of February 3 through 9 of 1963, December 22 through 27 of 1964, and January 27 through February 4 of 1965. USGS (1970) documents the results of these studies. The single storm of February 3 through 9 of 1963 accounted for approximately 50 percent of the total suspended load. This study determined that the average annual sediment discharge of the Palouse River at its mouth was approximately 1,433,376,000 kilograms (1,580,000 tons) per year and that the average annual sediment yield was approximately 168,129 kilograms per square kilometer (480 tons per square mile). However, the sediment yield ranged from 1,751 kilograms per square kilometer (5 tons per square mile) in the western part of the Palouse River Basin to 735,568 kilograms per square kilometer (2,100 tons per square mile) in the

central part of the basin having the loess hills. Sediment yield in the eastern part of the basin ranged from 161,124 kilograms per square kilometer (460 tons per square mile) to more than 350,270 kilograms per square kilometer (1,000 tons per square mile).

The Tucannon River Basin is similar to the Palouse River Basin in that the headwater areas are rugged volcanic highlands and the downstream portions are characterized by extensive loess deposits. Its sedimentation activity should somewhat qualitatively resemble that of the Palouse River Basin.

18. Prior Snake River Basin Sedimentation Studies

Verle C. Kaiser has conducted long-term studies starting in the mid-1930's of the annual erosion rates on standards plots throughout Whitman County, Washington; and his observations are among the very few sustained and systematic records of erosional processes in the general region. He concluded that:

1. Sediment delivery to the active channels is small relative to the amount of detached soil, with the difference deposited at the base of slopes and in swales.
2. Soil loss and sediment delivery are not in simple relation to rainfall or runoff but depend to a great degree on antecedent ground temperature and moisture conditions as well as on effective rainfall intensity.

His data also suggest that erosion rates may range through cycles of 10 to 15 years, which complicates the definition of "average" or "normal" rates of soil loss and sediment yields. His work is documented in Kaiser (1967) and the above descriptions of his studies were from USDA (1982, page 13).

McCool and Papendick (1975) also discuss the variability of sediment yields in Palouse-type watersheds. They noted that daily, seasonal, or annual variability in yields is very large in the small-grained dryland regions of the Pacific Northwest. Individual runoff events can account for more than half of the annual sediment yield. Sediment transport during a given year or a single large storm can be as large as the total of four or five other years. They recommended that intensive sampling during storms should be the basis of any field program. They concluded that "sampling programs based on weekly samples, even at stations with excellent streamflow records, can give extremely misleading results and sampling programs of only one or two years duration can also give extremely misleading results." McCool has also found that the distribution of frozen ground is a dominant factor in soil loss during individual storms (USDA, 1982).

From 1972 through 1979, the USGS gathered both suspended load and bedload information on the Snake and Clearwater rivers in response to recognized needs for this inflowing sediment information. The results of this data gathering effort are documented by USGS (1980).

Suspended sediment and bedload transport was monitored within the Tucannon River drainage basin from October 1979 through September 1980. Other than the studies accomplished on the Snake and Clearwater Rivers from 1972 through 1979, no bedload transport monitoring had been attempted in southeastern Washington prior to the Tucannon River monitoring. USDA (1982) documents the Tucannon River studies and should be consulted for more in-depth information on them.

The Corps developed an HEC-6 model of Lower Granite Reservoir as a tool to assist in reviewing the adequacy of the Lower Granite facility as related to sedimentation effects on navigation and flood control. The results of this study were documented by the Corps (1984). Further refinement of this initial work continued and in December 1992 another draft preliminary report was published which documented studies done as of that date (Corps, December 1992). The Corps also performed sedimentation studies in McNary Reservoir as part of the Tri-Cities levee studies. Results of these studies are documented by the Corps (May 1992a).

This page is intentionally left blank.

19. Present Lower Snake River and McNary Reservoir Sedimentation Studies

In support of the Lower Snake River Juvenile Salmon Migration Feasibility Study, sedimentation studies were conducted to evaluate the effects of breaching the four lower Snake River dams on sedimentation activity on the lower Snake River and the Columbia River between the Snake River confluence and McNary Dam. In downstream order, these dams are Lower Granite Dam, Little Goose Dam, Lower Monumental Dam, and Ice Harbor Dam. For these studies, the existing HEC-6 model for Lower Granite Reservoir was extended utilizing existing geometric information for the lower Snake River and the Columbia River between the Snake River confluence and McNary Dam. Recent channel sounding information taken downstream of Ice Harbor Dam was also incorporated into the model.

In addition, fluvial geomorphology studies were conducted on the lower Snake River. These investigations of channel morphology are presented in Appendix H, Fluvial Geomorphology. The objectives of these studies were to describe the physical characteristics and habitats of the pre-dam river, quantify the geomorphic features that describe salmon production areas, and to evaluate changes in the flow regime under near-dam breaching.

Most of the sediment that has accumulated within the lower Snake River reservoirs is located in Lower Granite because it has been the most upstream reservoir since 1975. From data collected, Ice Harbor has accumulated about 25 million cubic yards (MCYD) of sediment, Lower Monumental has about 4 MCYD, Little Goose has about 18 MCYD, and Lower Granite has about 84 MCYD. A sediment transport monitoring program was established for Lower Granite Reservoir in 1972, three years prior to Lower Granite Project's completion and pool raise in 1975, to quantify the inflowing sediment loads. This included both the suspended load and the bed load. USGS gathered data from 1972 through 1979 and has published this information in their report dated 1980 and titled "Sediment Transport in the Snake and Clearwater Rivers in the Vicinity of Lewiston, Idaho." This report should be consulted for further information regarding this inflowing sediment data collection program. In addition, the Walla Walla District Corps established a system of 71 sedimentation ranges, which is described in their Lower Granite Project Design Memorandum 39, dated 15 May 1975, entitled "Lake Sedimentation Ranges." Forty-four (44) ranges were initially established on the Snake River, 24 ranges initially established on the Clearwater River, and three established on Asotin Creek. This report (with revisions) should be consulted for further information regarding this sedimentation range program established in lower Granite Reservoir. Lower Granite's sedimentation ranges have been routinely surveyed several times since their initial survey in 1974, with follow-up surveys being done in 1976, 1977, 1979, 1982, 1983, 1984, 1985, 1986, 1987 (limited survey), 1989, 1992 (February, May, and July before and after 1992 Lower Granite Drawdown Test), 1995, 1996 (limited survey of only four ranges near Snake and Clearwater confluence), 1997, and 2000. In February 1984, the Walla Walla District Corps published an Interim Report entitled "Sedimentation Study- Interim Report- Lower Granite Project, Snake River, Washington and Idaho," which presents information regarding early sedimentation modeling studies conducted for the Lower Granite Project. In 1992, the Walla Walla District published a report entitled "Lower Granite Sedimentation Study, Preliminary Evaluation and Progress Report" as a follow-up to the 1984 study and report.

Until recently, minimal efforts had been accomplished on the other three Lower Snake River Projects with respect to sedimentation studies. In 1998, the first sedimentation ranges were established in Lake Sacajawea, with 37 ranges being designated between Snake River RMs 9.97 and 41.18. In 1999, 33 sedimentation ranges were established in Lake West between Snake River RMs 41.83 and 70.03. This augmented the sedimentation ranges established in 1969 in the vicinity of the Palouse River's confluence with the Snake River. This also augmented the sediment ranges established in 1976 in the vicinity of the Tucannon River's confluence and Alkali Creek's confluences with the Snake River. In 1998, 34 sedimentation ranges were established in Lake Bryan between Snake River RMs 70.70 and 104.26. This augmented sedimentation ranges previously established in the vicinity of Deadman Creek, Meadow Creek, and Schultz Bar. Some sedimentation ranges have been established and periodically monitored within McNary Reservoir, with 21 being established on the Columbia River between Columbia River RMs 293.40 and 343.94; and eleven being established on the Snake River between Snake River RMs 0.85 and 8.72. In addition, sedimentation ranges have been established on the Lower Walla Walla River and Lower Yakima River immediately upstream of their confluences with the Columbia River.

Numerous samples of sediment have been taken within Lower Granite Lake and analyzed by recognized soils laboratories, such as the Corps laboratory in Troutdale, Oregon and the Battelle Marine Research Laboratory located in Sequim, Washington. In 1985, the Battelle Marine Research Laboratory analyzed core samples taken in the vicinity of the Port of Clarkston located on the Snake River's left bank immediately downstream of the Snake and Clearwater River's confluence. In 1988, 1989, 1990, 1991, and 1993, the Corps Troutdale laboratory performed soils analyses on samples gathered within the Lower Granite Lake. These sample analyses have supported generalized conclusions with respect to sediment gradations noted within other river/reservoir systems. The noted mean sediment sizes generally decrease (become smaller) as one progresses further downstream within the reservoir. This change in sediment grain size is primarily due to the generally reducing flow velocities noted as one proceeds downstream within Lower Granite Lake, which is influenced by the increasing flow depths. As the flow velocities become smaller, the ability of the river to keep sediment in suspension decreases with the larger sediment sizes settling out first in the upstream end of the reservoir and progressively smaller grain sizes settling out further downstream in the reservoir. At its upstream end within Lower Granite Lake, near Snake River RM 142, a maximum flow depth of 20 feet represents an example of the changing flow section. In the vicinity of Silcott Island near Snake River RM 130, a representative maximum flow depth is 60 feet, and in the vicinity of Lower Granite Dam near Snake River RM 108 a representative maximum flow depth is 100 feet. Thus, the Snake River is approximately five times as deep near Lower Granite Dam as it is in the vicinity of the cities of Lewiston and Clarkston. It has been generally noted that the predominant grain sizes noted in samples taken upstream of Silcott Island have been sand-sized particles and the predominant grain sizes noted downstream of Silcott Island have been silt sized particles. However, predominant grain sizes have been noted to be highly variable and not easily categorized with respect to location. They have also been noted to vary with differing flow regimes. Generalizations about the characteristics of sediment must be made with great caution with necessary qualifications being clearly stated.

Section 2.5 of the Lower Snake River Juvenile Salmon Migration Feasibility Report/Environmental Impact Statement Appendix C, Water Quality discusses sediment quality studies accomplished on the lower Snake River since 1997 and should be consulted for further information regarding these studies.

Very limited sedimentation modeling was accomplished on the lower Snake River from the vicinity of its confluence with Asotin Creek downstream to its confluence with the Columbia River; and on the Columbia River between its confluence with the Snake River downstream to McNary Dam. A basic data set to model these reaches with the Corps HEC-6 Sediment Model was developed and the resulting model was utilized to make very generalized sedimentation studies along these reaches. It was generally noted during these modeling studies that the lower Snake River had the capability to erode and transport sediments along the entire reach upstream of Ice Harbor Dam. It was also noted that sediment deposition would occur downstream of Ice Harbor Dam, assuming that McNary Dam continued to operate at its normal pool elevation of 340 feet above mean sea level. Modeling of the 1992 Lower Granite Drawdown sedimentation activity was also accomplished utilizing the HEC-6 model with mixed success. The HEC-6 model tried utilizing the sediment range and sediment transport data gathered in the field during the 1992 Lower Granite Drawdown. HEC-6 has known limitations with respect to the modeling of the re-suspension and transport of silts and clays and this was noted during these modeling efforts. Because HEC-6 is a one-dimensional model, its predictions are averages made laterally across any given cross section along any given study reach of interest. No definitive conclusions were made as the result of these 1992 Lower Granite Drawdown modeling efforts, although much valuable insight was gained with respect to utilization of the HEC-6 model. During these modeling efforts, the program's author was able to make some adjustments to the computer code.

Rates of sedimentation activity are highly variable and dependent upon many geophysical factors that cannot be accurately predicted in advance of their occurrence. This makes future prediction of sedimentation activity highly speculative and subject to qualification. Examination of previous studies can provide insights with respect to this variability. For example, in 1969 USGS prepared the Water Supply Paper 1868 entitled "Sediment Transport by Streams in the Walla Walla River Basin, Washington and Oregon, July 1962-June 1965." They found during this time that "two runoff events resulting from rain and snowmelt on partially frozen ground produced 76 percent of the suspended sediment discharged from the basin during the (three year) study period" (page 2). USGS also found that "although the average annual runoff for the period 1962 to 1965 was only slightly less than that of 1951 to 1953, the sediment discharge was more than 50 percent greater" (page 26). This was due to more severe erosion occurring during the 1962 to 1965 period as a result of the floods of December 1964 and January to February 1965. USGS also reported that "the total duration of selected storm events composed only about 9 percent of the entire period of study. However, the combined runoff for selected storm events was about 38 percent of the total and the sediment transported was about 94 percent of the total" (page 23). In another report entitled "Sediment Transport by Streams in the Palouse River Basin, Washington and Idaho, July 1961 to June 1965," (Water Supply Paper 1899-C dated 1970) the USGS states that "the years during which precipitation is heavy are not necessarily those during which the sediment discharge is high. For example, the sediment load transported past Hooper in 1962-1963 was higher than that in 1964-1965, even though more precipitation occurred during the latter period" (page C34). USGS also states on page C34 that "less sediment was transported in the Palouse River at Hooper during the December 1964 storm than during the storm of February 1963 partly because (1) the soil mantle was frozen to great depths, and it was readily thawed by the warm temperatures, allowing water to percolate into the subsoil; (2) a lighter snowpack existed; (3) an inflow of cool air closely followed the initial rainfall and caused the runoff rate to decrease in some places; and (4) little rain fell on bare soil after the snowpack had been removed." These brief discussions illustrate the complexity of the runoff processes associated with sediment transport and the extreme difficulties in predicting soil erosion and sediment transport.

This page intentionally left blank.

20. Sedimentation Due to Lower Snake River Dam Breaching

If the four lower Snake River dams are breached, Lake Wallula, which is impounded by McNary Dam, will collect the majority of the sediments presently held behind the lower Snake River dams. Lake Wallula will also collect the majority of the annual sediment load naturally carried by the lower Snake River. Studies, data analysis, and professional judgements outlined in Section 19 were used to develop the sediment erosion, transport, and deposition information presented in this section. Under present conditions, Lower Granite Dam is capturing an average inflowing sediment load of approximately 2.3 to 3.1 million cubic meters (3 to 4 million cubic yards) per year that the lower Snake River is carrying due to various basin runoff processes. Tables 20-1 through 20-3 show the gradations of the inflowing bed load, suspended load, and total load, respectively. These tables are all based on sediment information contained in USGS (1980). Breaching of the four lower Snake River dams would allow this annual sediment load to be carried downstream to Lake Wallula, where the majority of the inflowing sediment would likely be deposited. The very finest silts and clays likely would be carried downstream through Lake Wallula with their ultimate destination being the Lower Columbia River estuary or the Pacific Ocean. Since the completion of Ice Harbor in 1962, approximately 76.5 to 114.7 million cubic meters (100 to 150 million cubic yards) of material has been deposited behind the four lower Snake River dams, with the approximate distribution shown in Table 20-4. A section of land, which is equivalent to 2.59 square kilometers (1 square mile), would be covered to a depth of one-third meter (1 foot) by 0.76 million cubic meters (1 million cubic yards) of sediment. Plates 20-1 through 20-5 show qualitative predictions of areas in Lake Wallula that are likely to experience notable sediment deposition, although it is emphasized that the entire reservoir downstream of the confluence of the Columbia and Snake rivers is susceptible to experiencing sedimentation effects. Interpretation of aerial photographs taken on April 14, 1983, of Lake Wallula sedimentation range information and of HEC-6 sedimentation model results was combined with professional judgment in the development of Plates 20-1 through 20-5. On the date of the aerial photographs, the mean daily discharge on the Columbia River at Priest Rapids Dam was 4,843 m3/second (171,000 cfs) and on the Snake River was approximately 2,124 m3/second (75,000 cfs) based on records taken at the Spalding and Anatone gaging stations. Due to the various uncertainties inherent in sedimentation processes, actual sedimentation experienced may or may not follow these predicted patterns.

The areas of deposition shown on Plates 20-1 through 20-5 assume that sediments released into Lake Wallula due to the breaching of all four lower Snake River dams have had sufficient opportunity to be transported down the Snake River and to be redistributed within Lake Wallula. This process will occur over a period of several years after the breaching of all four dams. The depositional areas shown on Plates 20-1 through 20-5 will probably experience the most notable deposition of sediments, which will probably be on the order of a meter or a few feet in depth. However, it is emphasized that the entire Lake Wallula area downstream of the Snake River's confluence with the Columbia River is susceptible to sedimentation activity and potentially could experience sediment deposition on the order of one-third meter (1 foot) outside of the delineated areas. It is also emphasized that sedimentation activity is highly dependent on localized flow patterns and velocities. These localized effects were considered only in a generalized sense during the development of Plates 20-1 through 20-5 and, therefore, actual sedimentation experienced after dam breaching may differ from these generalized maps.

Table 20-1. Snake and Clearwater Rivers Suspended Load Summary - Sediment Inflow into Lower Granite Lake: Particle Size Distribution and Percentage of Total Sample by Weight

Grain Size Range (millimeters)	Snake River Inflow (Percent)	Clearwater River Inflow (Percent)	Composite Inflow (Percent)
1.0-2.0	0.03	0.01	0.02
0.5-1.0	0.66	1.59	0.97
0.25-0.5	10.07	14.82	11.65
0.125-0.25	19.72	14.14	17.88
0.0625-0.125	17.20	10.07	14.83
0.031-0.0625	7.78	5.33	6.96
0.016-0.031	9.57	9.87	9.67
0.008-0.016	8.86	11.34	9.68
0.004-0.008	7.94	6.79	7.56
0.002-0.004	4.69	5.46	4.94
<0.002	13.48	20.58	15.84
Percentage Sum	100.00	100.00	100.00

Data Source: United States Department of the Interior
United States Geological Survey (USGS) Boise, Idaho
Sediment Transport in the Snake and Clearwater Rivers In the Vicinity of Lewiston, Idaho
Michael L. Jones and Harold R. Seitz
Open File Report 80-690, August 1980

All percentages computed on a weight basis using suspended load data gathered by the USGS on the Snake River at Anatone, Washington (USGS Station Number 13334300) and on the Clearwater River at Spalding, Idaho (USGS Station Number 13342500) from 1972 through 1979, and published in the above referenced data source. These data represent grain size information for sediments actively being transported by the rivers as suspended sediment load.

Table 20-2. Snake and Clearwater Rivers Bed Load Summary – Sediment Inflow into Lower Granite Lake: Particle Size Distribution and Percentage of Total Sample by Weight

Grain Size Range (millimeters)	Snake River Inflow (Percent)	Clearwater River Inflow (Percent)	Composite Inflow (Percent)
90-128	3.57	4.44	3.83
64-90	12.36	7.11	10.82
45-64	9.63	10.79	9.97
32-45	9.40	3.96	7.79
22.6-32	8.67	3.49	7.14
16-22.6	5.76	1.77	4.58
11.3-16	3.93	1.17	3.11
8-11.3	1.54	0.91	1.35
5.7-8	0.86	0.74	0.82
4-5.7	0.65	0.52	0.61
2.8-4	0.74	0.53	0.68
2-2.8	0.77	0.41	0.66
1.4-2	1.02	0.46	0.85
1-1.4	1.40	0.91	1.26
0.71-1	3.36	5.29	3.93
0.50-0.71	10.40	20.97	13.53
0.35-0.50	12.59	17.85	14.15
0.25-0.35	9.67	13.86	10.92
0.18-0.25	2.85	3.98	3.18
0.12-0.18	0.52	0.59	0.54
0.09-0.12	0.15	0.10	0.13
0.06-0.09	0.08	0.06	0.07
<0.06	0.08	0.09	0.08
Percentage Sum	100.00	100.00	100.00

Data Source: United States Department of the Interior
United States Geological Survey (USGS) Boise, Idaho
<u>Sediment Transport in the Snake and Clearwater Rivers In the Vicinity of Lewiston, Idaho</u>
Michael L. Jones and Harold R. Seitz
Open File Report 80-690, August 1980

All percentages are computed on a weight basis using bed load data gathered by the USGS on the Snake River at Anatone, Washington (USGS Station Number 13334300) and on the Clearwater River at Spalding, Idaho (USGS Station Number 13342500) from 1972 through 1979, and published in the above referenced data source. These data represent grain size information for sediments actively being transported by the rivers as bed load.

Table 20-3. Snake and Clearwater Rivers Total Load Summary – Sediment Inflow into Lower Granite Lake: Particle Size Distribution and Percentage of Total Sample by Weight

Grain Size Range (millimeters)	Snake River Inflow (Percent)	Clearwater River Inflow (Percent)	Composite Inflow (Percent)
90-128	0.19	0.20	0.20
64-90	0.65	0.32	0.55
45-64	0.51	0.49	0.50
32-45	0.50	0.18	0.40
22.6-32	0.46	0.16	0.36
16-22.6	0.31	0.08	0.23
11.3-16	0.21	0.05	0.16
8-11.3	0.08	0.04	0.07
5.7-8	0.05	0.04	0.04
4-5.7	0.04	0.03	0.03
2.8-4	0.04	0.02	0.04
2-2.8	0.04	0.02	0.04
1.0-2	0.16	0.07	0.13
0.50-1.0	1.36	2.71	1.80
0.25-0.50	10.72	15.59	12.33
0.125-0.25	18.85	13.70	17.15
0.0625-0.125	16.30	9.62	14.09
0.031-0.0625	7.36	5.09	6.61
0.016-0.031	9.06	9.42	9.18
0.008-0.016	8.39	10.83	9.19
0.004-0.008	7.52	6.48	7.18
0.002-0.004	4.44	5.21	4.69
<0.002	12.76	19.65	15.03
Percentage Sum	100.00	100.00	100.00

Data Source: United States Department of the Interior
United States Geological Survey (USGS) Boise, Idaho
Sediment Transport in the Snake and Clearwater Rivers In the Vicinity of Lewiston, Idaho
Michael L. Jones and Harold R. Seitz
Open File Report 80-690, August 1980

All percentages are computed on a weight basis using the sum of suspended and bed load data gathered by the USGS on the Snake River at Anatone, Washington (USGS Station Number 13334300) and on the Clearwater River at Spalding, Idaho (USGS Station Number 13342500) from 1972 through 1979, and published in the above referenced data source. This data represents grain size information for sediments actively being transported by the rivers as a combination of both bed load and suspended load.

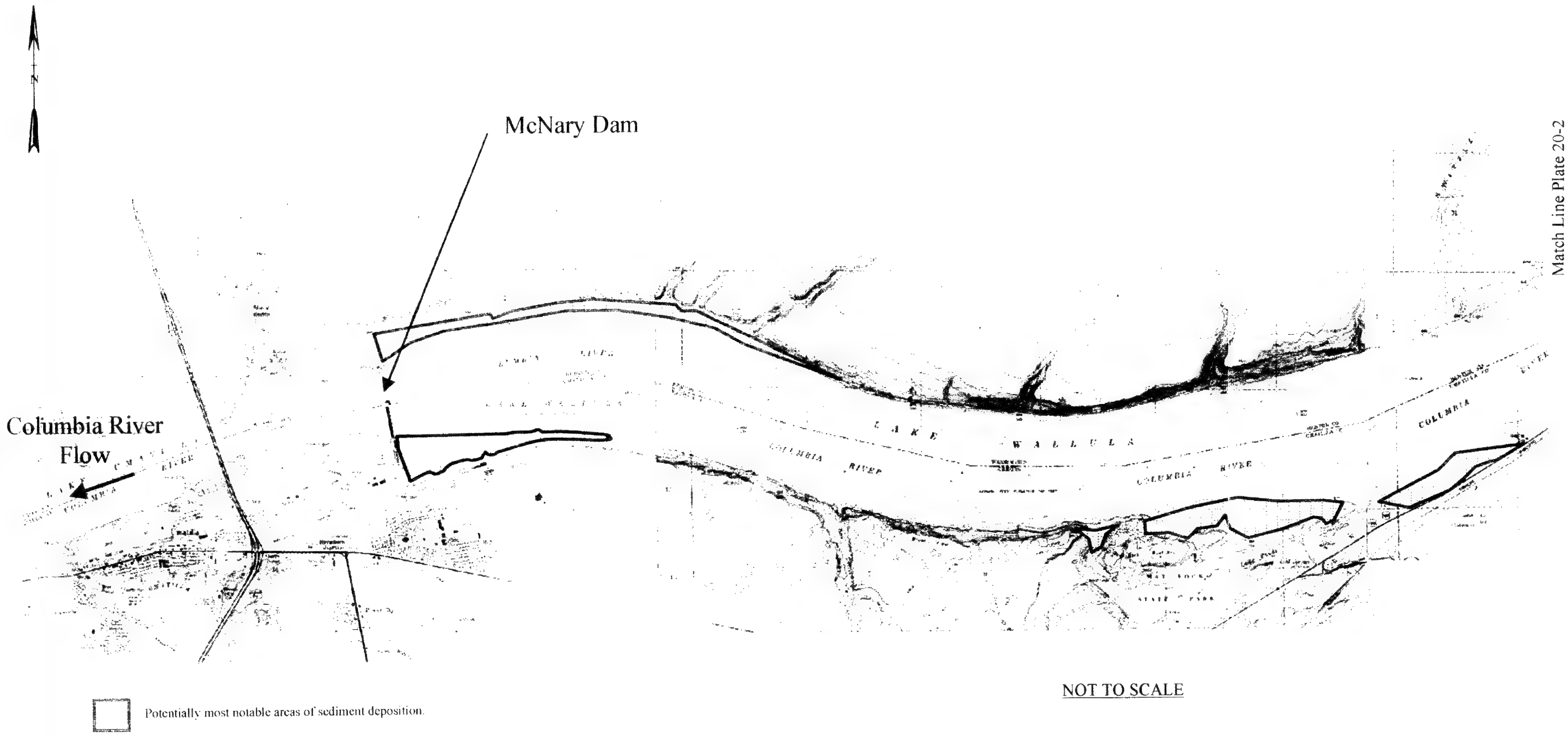
Table 20-4. Distribution of Sediment Carried by the Lower Snake River and Deposited in McNary and Four Lower Snake River Reservoirs From 1953 through 1998

Facility	Date In Service	Dates Facility Impounded Sediment	Estimated Volume Sediment Impounded
McNary	1953	1953-1961 (9 years)	20.6-27.7 MCMTR (27-36 MCYD)
Ice Harbor	1962	1962-1968 (7 years)	16.1-21.4 MCMTR (21-28 MCYD)
Lower Monumental	1969	1969-1970 (1 year)	2.3-3.1 MCMTR (3-4 MCYD)
Little Goose	1970	1971-1975 (5 years)	11.5-15.3 MCMTR (15-20 MCYD)
Lower Granite	1975	1975-1998 (24 years)	55.1-73.4 MCMTR (72-96 MCYD)
<u>Totals:</u>	**(McNary and Lower Snake)**	**46 Years**	**105.5-140.7 MCMTR (138-184 MCYD)**
	(Lower Snake Facilities Only)	**37 Years**	**84.9-113.2 MCMTR (111-148 MCYD)**

Notes:

1. MCMTR is abbreviation for million cubic meters. MCYD is abbreviation for million cubic yards. Multiply by 0.7646 to convert from million cubic yards (MCYD) to million cubic meters (MCMTR).
2. Lower Snake River assumed to carry approximately 2.3 to 3.1 million cubic meters (three to four million cubic yards) of sediment per year, on the average. This amount is based on suspended sediment and bed load data collected from 1972 through 1979 on the Snake and Clearwater rivers upstream of Lower Granite Reservoir. The actual amount varies from year to year with climate and basin conditions, and can not be accurately predicted in advance.
3. Time in service dates and time projects collected sediment approximated to the nearest year.
4. Sediment contributions by Snake River basin watersheds downstream of the confluence of the Snake River and Clearwater River are not reflected in sediment volumes listed in this table.
5. Sediment contributions into McNary Reservoir (Lake Wallula) by the Yakima River, Columbia River, Walla Walla River, and other tributaries are not included in the above table. This table only includes sediments transported by the lower Snake River.

This page is intentionally left blank.



Notes:

1. Areas of deposition are delineated assuming that sediments released into McNary Reservoir due to the removal of all four Lower Snake River dams have had sufficient opportunity to be transported down the Snake River and redistributed within McNary Reservoir. This process will occur over a period of several years after removal of all four dams.

2. Delineated areas probably will experience the most notable deposition of sediments, probably on the order of a few feet of depth. However, the entire McNary Reservoir downstream of the Snake River confluence is susceptible to sedimentation activity due to the removal of the four Lower Snake River dams, and potentially could experience deposition on the order of approximately one foot outside of the delineated areas.

3. Sedimentation activity is highly dependent on localized flow patterns and velocities. These localized effects were considered only in a generalized sense during map preparation and therefore actual sedimentation experienced after dam removal may differ from these generalized maps.

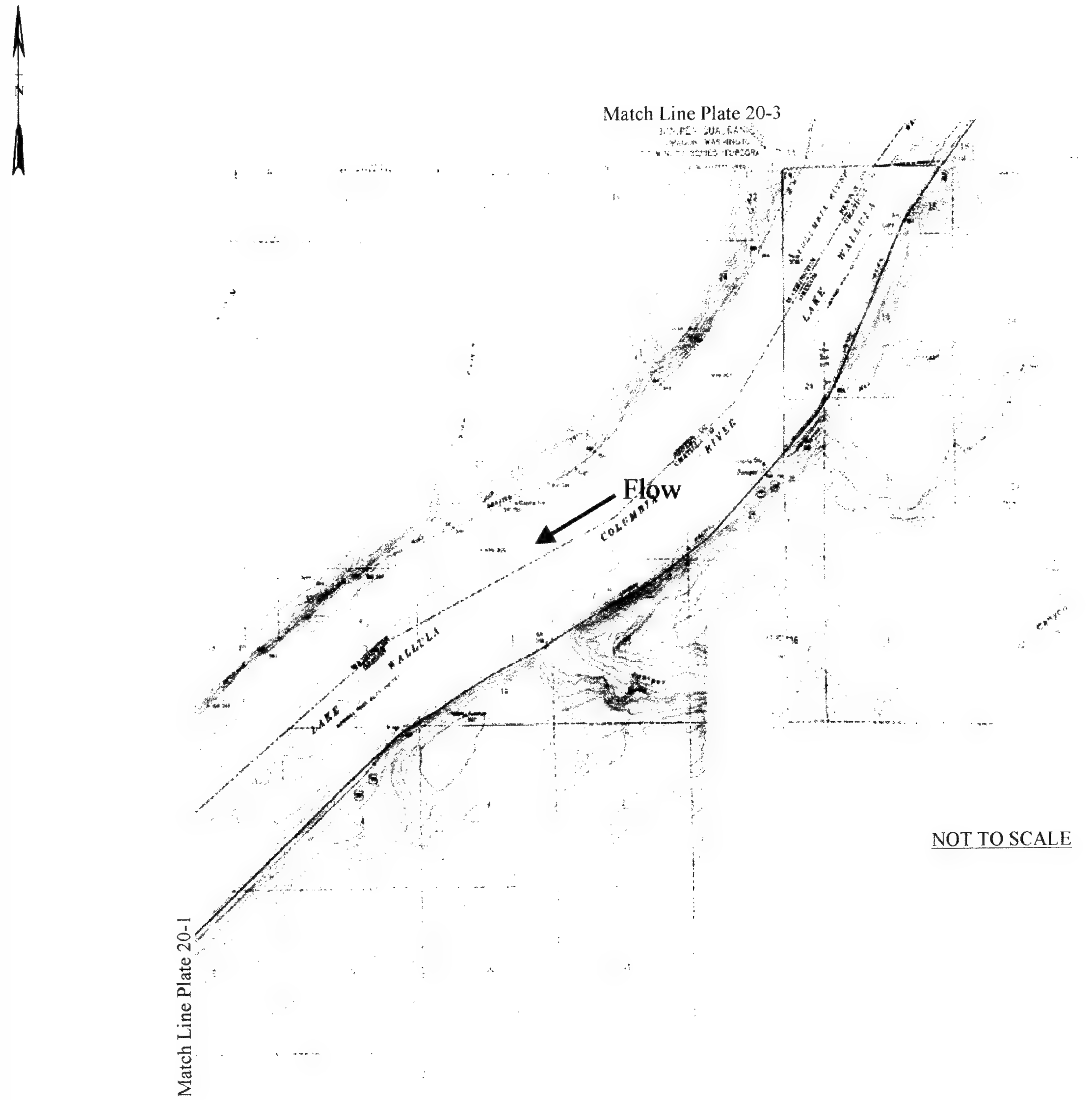
COLUMBIA RIVER BASIN
COLUMBIA RIVER

McNARY RESERVOIR
POTENTIAL SEDIMENTATION DUE TO LOWER SNAKE RIVER DAM REMOVAL
McNary Dam and Lake Wallula

U.S. ARMY ENGINEER DISTRICT
WALLA WALLA - HYDROLOGY BRANCH

DESIGNED	DRAWN	DATE
SPANGRUDE	C. KOCH	OCT 1998

PLATE 20-1



Potentially most notable areas of sediment deposition.

Notes:

1 Areas of deposition are delineated assuming that sediments released into McNary Reservoir due to the removal of all four Lower Snake River dams have had sufficient opportunity to be transported down the Snake River and redistributed within McNary Reservoir. This process will occur over a period of several years after removal of all four dams.

2 Delineated areas probably will experience the most notable deposition of sediments, probably on the order of a few feet of depth. However, the entire McNary Reservoir downstream of the Snake River confluence is susceptible to sedimentation activity due to the removal of the four Lower Snake River dams, and potentially could experience deposition on the order of approximately one foot outside of the delineated areas.

3 Sedimentation activity is highly dependent on localized flow patterns and velocities. These localized effects were considered only in a generalized sense during map preparation and therefore actual sedimentation experienced after dam removal may differ from these generalized maps.

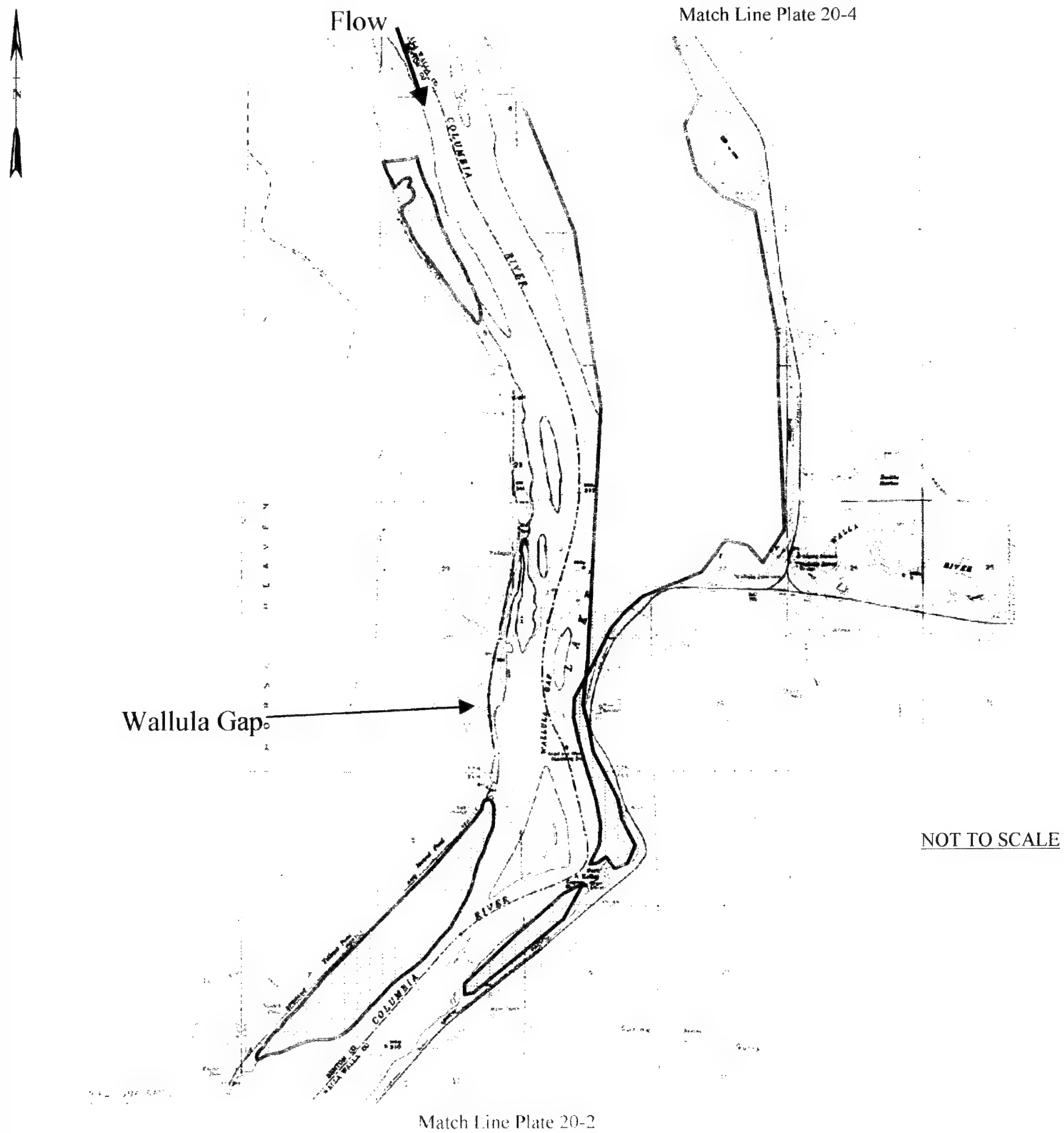
COLUMBIA RIVER BASIN
COLUMBIA RIVER

McNARY RESERVOIR
POTENTIAL SEDIMENTATION DUE TO LOWER SNAKE RIVER DAM REMOVAL
Upper Lake Wallula

U.S. ARMY ENGINEER DISTRICT
WALLA WALLA - HYDROLOGY BRANCH

DESIGNED	DRAWN	DATE
SPANGRUDE	C. KOCH	OCT 1998

PLATE 20-2



Potentially most notable areas of sediment deposition

Notes:

1 Areas of deposition are delineated assuming that sediments released into McNary Reservoir due to the removal of all four Lower Snake River dams have had sufficient opportunity to be transported down the Snake River and redistributed within McNary Reservoir. This process will occur over a period of several years after removal of all four dams.

2 Delineated areas probably will experience the most notable deposition of sediments, probably on the order of a few feet of depth. However, the entire McNary Reservoir downstream of the Snake River confluence is susceptible to sedimentation activity due to the removal of the four Lower Snake River dams, and potentially could experience deposition on the order of approximately one foot outside of the delineated areas.

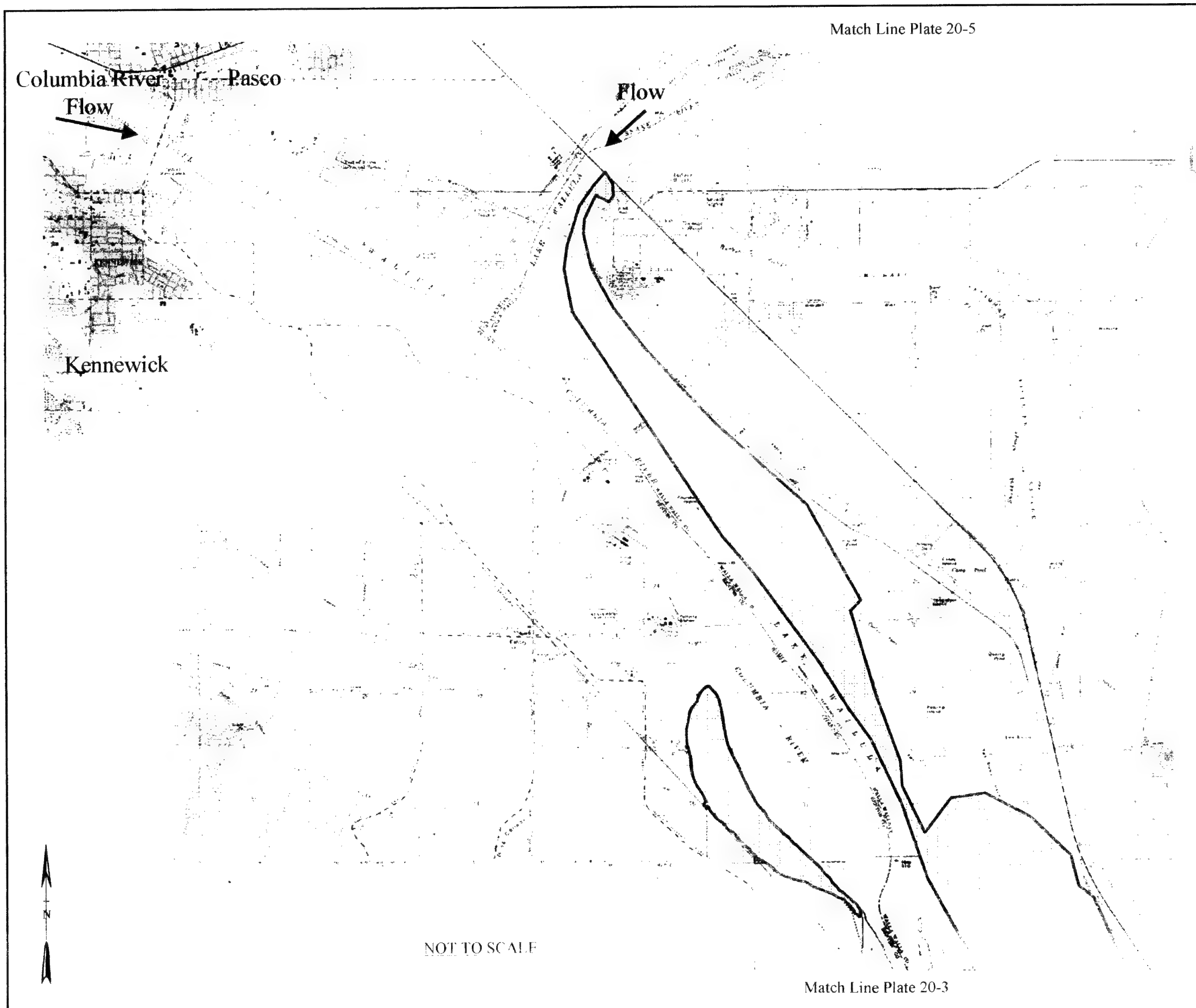
3 Sedimentation activity is highly dependent on localized flow patterns and velocities. These localized effects were considered only in a generalized sense during map preparation and therefore actual sedimentation experienced after dam removal may differ from these generalized maps.

COLUMBIA RIVER BASIN
COLUMBIA RIVER

McNARY RESERVOIR
POTENTIAL SEDIMENTATION DUE TO LOWER SNAKE RIVER DAM REMOVAL
Wallula Gap

U.S. ARMY ENGINEER DISTRICT
WALLA WALLA - HYDROLOGY BRANCH

DESIGNED	DRAWN	DATE
SPANGRUDI	C. KOCH	OCT 1998



Potentially most notable areas of sediment deposition.

Notes:

1. Areas of deposition are delineated assuming that sediments released into McNary Reservoir due to the removal of all four Lower Snake River dams have had sufficient opportunity to be transported down the Snake River and redistributed within McNary Reservoir. This process will occur over a period of several years after removal of all four dams.

2. Delineated areas probably will experience the most notable deposition of sediments, probably on the order of a few feet of depth. However, the entire McNary Reservoir downstream of the Snake River confluence is susceptible to sedimentation activity due to the removal of the four Lower Snake River dams, and potentially could experience deposition on the order of approximately one foot outside of the delineated areas.

3. Sedimentation activity is highly dependent on localized flow patterns and velocities. These localized effects were considered only in a generalized sense during map preparation and therefore actual sedimentation experienced after dam removal may differ from these generalized maps.

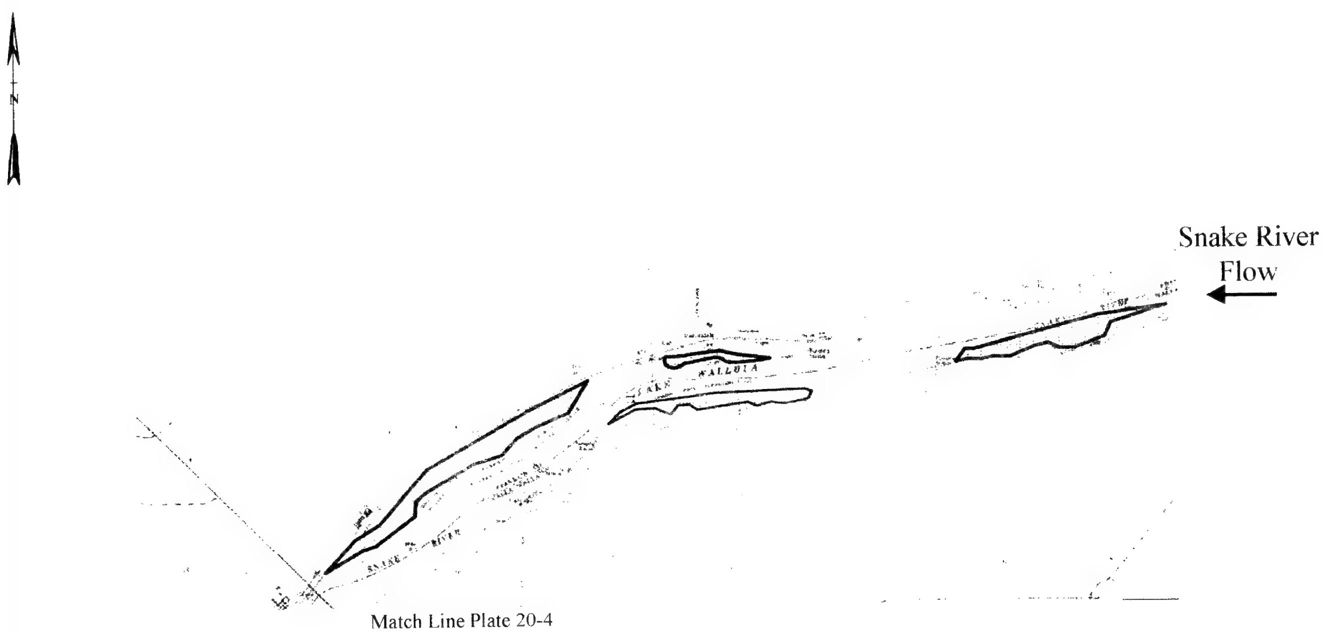
COLUMBIA RIVER BASIN
COLUMBIA RIVER

McNARY RESERVOIR
POTENTIAL SEDIMENTATION DUE TO LOWER SNAKE RIVER DAM REMOVAL
Columbia-Snake River Confluence

U.S. ARMY ENGINEER DISTRICT
WALLA WALLA - HYDROLOGY BRANCH

DESIGNED	DRAWN	DATE
SPANGRUDE	C. KOCH	OCT 1998

PLATE 20-4



NOT TO SCALE

Potentially most notable areas of sediment deposition.

Notes:

1. Areas of deposition are delineated assuming that sediments released into McNary Reservoir due to the removal of all four Lower Snake River dams have had sufficient opportunity to be transported down the Snake River and redistributed within McNary Reservoir. This process will occur over a period of several years after removal of all four dams.

2. Delineated areas probably will experience the most notable deposition of sediments, probably on the order of a few feet of depth. However, the entire McNary Reservoir downstream of the Snake River confluence is susceptible to sedimentation activity due to the removal of the four Lower Snake River dams, and potentially could experience deposition on the order of approximately one foot outside of the delineated areas.

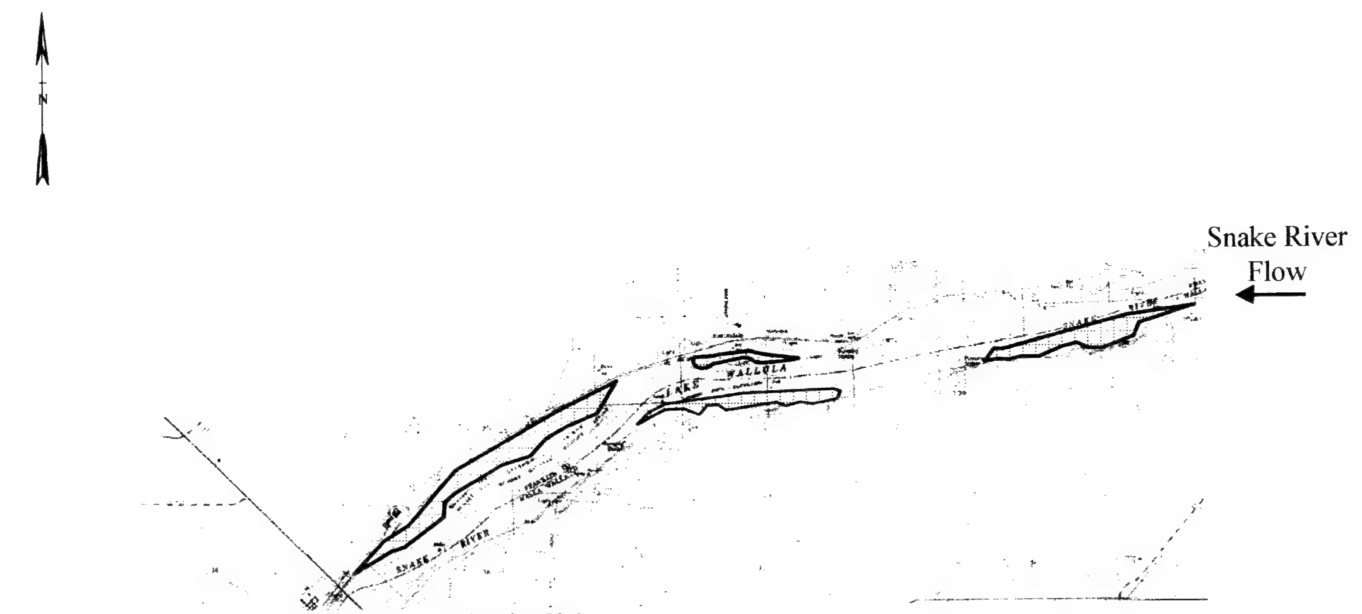
3. Sedimentation activity is highly dependent on localized flow patterns and velocities. These localized effects were considered only in a generalized sense during map preparation and therefore actual sedimentation experienced after dam removal may differ from these generalized maps.

COLUMBIA RIVER BASIN
COLUMBIA RIVER

McNARY RESERVOIR
POTENTIAL SEDIMENTATION DUE TO LOWER SNAKE RIVER DAM REMOVAL
Immediate Vicinity
of the Columbia-Snake River Confluence
U.S. ARMY ENGINEER DISTRICT
WALLA WALLA - HYDROLOGY BRANCH

DESIGNED	DRAWN	DATE
SPANGRUDE	C. KOCH	OCT 1998

PLATE 20-5



NOT TO SCALE

Potentially most notable areas of sediment deposition.

Notes:

1. Areas of deposition are delineated assuming that sediments released into McNary Reservoir due to the removal of all four Lower Snake River dams have had sufficient opportunity to be transported down the Snake River and redistributed within McNary Reservoir. This process will occur over a period of several years after removal of all four dams.

2. Delineated areas probably will experience the most notable deposition of sediments, probably on the order of a few feet of depth. However, the entire McNary Reservoir downstream of the Snake River confluence is susceptible to sedimentation activity due to the removal of the four Lower Snake River dams, and potentially could experience deposition on the order of approximately one foot outside of the delineated areas.

3. Sedimentation activity is highly dependent on localized flow patterns and velocities. These localized effects were considered only in a generalized sense during map preparation and therefore actual sedimentation experienced after dam removal may differ from these generalized maps.

COLUMBIA RIVER BASIN
COLUMBIA RIVER

McNARY RESERVOIR
POTENTIAL SEDIMENTATION DUE TO LOWER SNAKE RIVER DAM REMOVAL
Immediately Upstream
of the Columbia-Snake River Confluence
U.S. ARMY ENGINEER DISTRICT
WALLA WALLA - HYDROLOGY BRANCH

DESIGNED	DRAWN	DATE
SPANGRUDE	C. KOCH	OCT 1998

PLATE 20-5

If the four lower Snake River dams are breached, approximately 50 percent (one half) of the previously deposited materials will be eroded and transported by the Snake River within the first few years following dam breaching. The eroded materials will most likely be re-deposited in Lake Wallula between the Snake River and Wallula Gap. Since McNary Dam's backwater pool extends up to Ice Harbor Dam, the very coarsest cobble materials could start depositing in the vicinity of Ice Harbor Dam, although they could later be subject to re-suspension and further transport downstream to Lake Wallula by floods, which exceed the flows experienced at the time of their original deposition. The coarsest sediments would be deposited first, with the sediment deposits becoming progressively finer as they are transported further downstream into Lake Wallula. Since these materials were once able to be previously deposited behind the lower Snake River dams and since the flow velocities in Lake Wallula are generally lower than the Snake River's velocities, it is very likely that most of these sediments will also be deposited in Lake Wallula rather than being transported downstream of McNary Dam. The remainder of the sediments previously deposited upstream of the lower Snake River dams and not eroded within the first few years of dam breaching would be subject to long-term erosion by wind and precipitation and could eventually also be transported downstream by the Snake River to Lake Wallula.

The lower Snake River downstream of Lewiston, Idaho, annually transports approximately 2.3 to 3.1 million cubic meters (3 to 4 million cubic yards) of new sediments that have been eroded from its drainage basin. If the four lower Snake River dams are breached, this material would be transported by the Snake River downstream to the Columbia River. Since the lower Snake facilities would no longer be available to capture sediments inflowing annually, all but the finest suspended sediments carried by the Snake River would likely deposit within Lake Wallula. The very fine sediments that do not deposit in Lake Wallula would continue to be transported downstream of McNary Dam, with their ultimate destination likely being the Columbia River estuary or the Pacific Ocean.

The sediment presently impounded by the four lower Snake River dams that would accumulate within Lake Wallula (50 to 75 millions cubic yards of material) within a few years after lower Snake River dam breaching and continue at an average rate of 2.3 to 3.1 million cubic meters (3 to 4 million cubic yards) per year due to the Snake River's annual sediment load would eventually expect to impact the water surface profile of Lake Wallula. Freeboard for the Tri-Cities levees could then be potentially impacted at some point in the future. The degree of potential impact and that date in the future cannot be predicted with any reasonable accuracy; but it would be correctly influenced by where the sediment accumulates and whether any dredging would be done to alleviate the problem.

Both this appendix and Appendix H, Fluvial Geomorphology (Section 4.5) discuss sediment transport. A 5 year time is referenced by both the time period that it would take to erode and transport the Lower Granite sediment. Appendix H (Figure 4-18) indicates that most of the sediment would be removed in 2 years or less. That rate will be dependent upon flow rates, climatic condition, and the manner in which the lower Snake River dams would be breached. This appendix has focused more on the time that it will take to transport the lower Snake River sediment into McNary Reservoir and that is the reason that this appendix indicates a little longer overall time period for transport and deposition.

There are many uncertainties associated with the erosion and resuspension, the transport, and then the deposition of the Lower Granite and remaining lower Snake River sediment accumulations into

McNary Reservoir. The order and timing for breaching of the lower Snake River dams along with the magnitude of upstream flows entering the lower Snake River during breaching will determine the actual timing of the sediment transport and both are unknown at this time. Whether the sediment is transported into McNary Reservoir in 2 years or 5 years is not expected to influence the decision on how to sequence the dam breaching. Performing additional studies or data analysis for the sediment transport before the dam breaching are not expected to significantly improve transport and deposition estimates. The current plan is to monitor sediment transport during breaching (if breaching occurred) and then dredge or correct problems as they arise. Section 26 outlines the monitoring plan and expected costs.

21. Discussion of Dam Breaching Effects on Fish Passage After Dam Breaching

Dr. Barton Evermann, a former ichthyologist with the United States Fish Commission, described some of the Snake River's characteristics in his paper entitled "A Preliminary Report Upon Salmon Investigations in Idaho in 1894." On pages 257 to 259, he describes the Snake River between Twin Falls and Lower Salmon Falls. In this report, he states that "salmon can not possibly ascend the Snake River farther than the foot of Shoshone Falls; and it was also believed that certain falls below Shoshone Falls (Auger Falls, Upper Salmon Falls, and Lower Salmon Falls) interfere seriously with the ascent of salmon." Lower Salmon Falls is near Snake River, kilometer 922 (river mile 573), Upper Salmon Falls is near Snake River kilometer 937 (river mile 582), Auger Falls is near Snake River kilometer 977 (river mile 607), Shoshone Falls is near Snake River kilometer 990 (river mile 615), and Twin Falls is near Snake River kilometer 993 (river mile 617). Between Lower Salmon Falls and Upper Salmon Falls, the Snake River drops approximately 33.5 meters (110 feet) in 14.5 kilometers (9 miles), for an average slope of 2.3 meters per kilometer (12 feet per mile). Between Upper Salmon Falls and Auger Falls, the Snake River drops approximately 42.7 meters (140 feet) in 40.2 kilometers (25 miles) for an average slope of 1.1 meters per kilometer (5.6 feet per mile). Between Auger Falls and Shoshone Falls, the Snake River drops approximately 61 meters (200 feet) in 12.9 kilometers (8 miles) for an average slope of 4.7 meters per kilometer (25 feet per mile). The average slope for the Snake River between the Clearwater confluence and Shoshone Falls is approximately 1.0 meter/kilometer (5.3 feet per mile). These slopes are all greater than the Snake River's average slope computed between its confluences with the Clearwater and Columbia rivers. Since salmon were once able to swim through the lower Snake River before construction of the four lower Snake River dams, it may be assumed that breaching of the dams and the re-emergence of rapids and falls will have no impact on their ability to again swim through this reach of the river.

This page is intentionally left blank.

22. McNary Reservoir (Lake Wallula) Sedimentation Generalized Description

The distance from the Snake and Columbia Rivers' confluence downstream to McNary Dam is approximately 53.1 kilometers (33 miles) as measured along the Columbia River's centerline. The distance between their confluence and Wallula Gap is approximately 16.1 kilometers (10 miles). The Columbia River's width along this 16.1-kilometer (10-mile) reach is approximately 3,048 meters (10,000 feet). Assuming an average width of 3,048 meters (10,000 feet) and an average effective depth for water conveyance of 9.1 meters (30 feet) results in an approximate average flow area of 27,870 square meters (300,000 square feet). Because the average annual discharge of the Columbia River at McNary Dam is approximately 5,664 m^3/second (200,000 cfs), the average flow velocity for this discharge along this reach is on the order of 0.3 meter (1 foot) per second. Based on Figure 2.46, found on page 102 of American Society of Civil Engineers (ASCE) Manual 54, Sedimentation Engineering, the sediment sizes potentially able to be transported through this reach of McNary Reservoir might likely be those having a mean diameter less than 1.0 millimeter. Assuming an average water velocity of 0.3 meter (1 foot) per second as previously computed, the approximate time required to travel the 16.1-kilometer (10-mile) distance from the confluence downstream to Wallula Gap is 14.6 hours (52,800 seconds). Assuming an average distance of vertical particle fall of 15.2 meters (50 feet) over a time period of 52,800 seconds results in an average fall velocity of approximately 0.029 centimeter per second. Using Figure 2.2, found on page 25 of ASCE Manual 54, a particle approximately 0.02 millimeter in diameter will fall at approximately 0.029 centimeters per second in water at 12 degrees C (54 degrees F). Therefore it is quite likely that particles greater than 0.02 millimeter in diameter could potentially settle out in McNary Reservoir upstream of Wallula Gap and those smaller than 0.02 millimeter could likely be carried downstream and pass through McNary. This is because the Columbia River narrows drastically to a width of approximately 1,524 meters (5,000 feet) downstream of Wallula Gap, which translates to increased water flow velocities and increased sediment transport capabilities downstream of Wallula Gap. The diameter of 0.02 millimeter is approximately that of the finest particles contained in the medium silts size class. Therefore, it is quite likely that materials in the fine and very fine silts size classes, in all clay size classes, as well as colloidal materials transported past Wallula Gap will also subsequently pass through McNary as the Columbia River's suspended sediment load. The fact that McNary Dam's spillway crests are approximately 15.2 meters (50 feet) above the Columbia River's streambed make it highly unlikely that bedload materials will pass through McNary Project.

This generalized description of potential sedimentation activity within Lake Wallula is valid for either the condition of the four lower Snake River dams being in place or for any combination of lower Snake River dam breaching. Lake Wallula has the capacity to trap all but the finest sediments, as previously described, and it is extremely unlikely that any of the Columbia River's bedload will pass through McNary Dam due to the vertical distance from the Columbia River's streambed up to McNary Dam's spillway crest. Therefore it is highly unlikely that the breaching of the lower Snake River dams will cause appreciable sediment deposition downstream of McNary Dam, since it appears that McNary has the ability to capture all but the finest suspended sediments. It is extremely unlikely that these suspended sediments will deposit upstream of the Columbia River estuary.

This page is intentionally left blank.

23. Sedimentation Downstream of McNary

Since only particles finer than the medium silts size class will likely pass through McNary, the sources of coarser materials downstream of McNary Dam as well as additional fine materials must be local runoff and streams that enter the Columbia River downstream of McNary Dam. Some examples of such tributaries are the Umatilla River, the John Day River, the Deschutes River, the Hood River, and the Willamette River. The Umatilla River enters the Columbia River along its left bank approximately 3.2 kilometers (2 miles) downstream of McNary Dam. Its suspended and bed loads can potentially cause sedimentation problems in the vicinity of this confluence because of reduced flow velocities downstream of the confluence. The Umatilla River's drainage area is approximately 5,931 square kilometers (2,290 square miles), its average discharge is 13.3 m^3/second (469 cfs), and its maximum discharge is approximately 560.7 m^3/second (19,800 cfs). The John Day River's drainage area is approximately 19,684 square kilometers (7,600 square miles), its average discharge is 59.0 m^3/second (2,085 cfs), and its maximum discharge is approximately 1,212.1 m^3/second (42,800 cfs). The Deschutes River's drainage area is approximately 27,195 square kilometers (10,500 square miles), its average discharge is approximately 164.4 m^3/second (5,805 cfs), and its maximum discharge is approximately 1,990.9 m^3/second (70,300 cfs). The Hood River's drainage area is approximately 722.6 square kilometers (279 square miles), its average discharge is 28.7 m^3/second (1,015 cfs), and its maximum discharge is 659.9 m^3/second (23,300 cfs). The Willamette River's drainage area is approximately 28,749 square kilometers (11,100 square miles), its average discharge is 888.4 m^3/second (31,370 cfs), and its maximum discharge noted prior to flooding in 1996 is 8,014.6 m^3/second (283,000 cfs).

This page is intentionally left blank.

24. Water Supply Intakes in McNary Pool

Based on qualitative inspection of aerial photographs, topographic mapping, and available sediment range surveys, the left (east) bank of the Columbia River from the point of its confluence with the Snake River downstream to its confluence with the Walla Walla River near Wallula Gap appears to be very susceptible to sediment deposition. Actual deposition depths and patterns likely to be experienced are difficult to predict in advance, due to the complex nature of sedimentation activity and its dependence on localized flow patterns. To avoid problems due to potential sediment deposition, water intakes should be located as far above the streambed as practical and should be located in areas having noticeable flow velocities high enough to discourage the deposition of sediment. Locating water intakes in quiescent areas is not advisable, due to the potential for higher rates of sediment deposition.

This page is intentionally left blank.

25. Time Required to Reach a New Equilibrium After Dam Breaching

Due to many variables, primarily related to climate, it is difficult to predict the time needed for landscape recovery after dam breaching. However, generalized qualitative predictions can be realistically made using information available both within the study area and from published literature. In January 1973, the Lewiston Hydroelectric Project, located on the Clearwater River approximately 8.05 kilometers (5 miles) east of Lewiston, Idaho, was removed as part of the Lower Granite Lock and Dam construction process. Sediment range surveys were made upstream of this relatively small project in 1971 (before dam breaching) and in 1975 and 1982 (after dam breaching). These surveys indicate that most of the erosion occurred between dam breaching in 1973 and the first survey in 1975. Some relatively minor erosion occurred between the 1975 and 1982 surveys. This information suggests that a significant portion of the channel sediment erosion will have occurred within about 2 to 5 years after dam breaching. Erosion of sediments not subject to annual riverine erosive action, but subject to only weather erosion such as that from precipitation and wind action, could take many years to accomplish and is extremely hard to assess because of the uncertainties in weather prediction.

The Executive Summary of the Department of Interior, Bureau of Reclamation, report entitled "Sediment Analysis and Modeling of the River Erosion Alternative," written as part of the Elwha River Ecosystem and Fisheries Restoration Project in October 1996, gives this information concerning sedimentation activity in relation to the breaching of the Elwha and Glines Canyon dams: "model results predicted that 15 to 35 percent of the coarse sediment (sand, gravel, and cobbles) and about half (50 percent) of the fine sediment (silt and clay sized particles) would be eroded from the two reservoirs. The remaining sediment would be left behind along the reservoir margins as a series of terraces. Fine sediment concentrations released from the reservoirs would be high during periods of dam breaching, typically 200 to 1000 ppm but occasionally as high as 30,000 to 50,000 ppm. Release concentrations would be relatively low (less than 200 ppm) during periods of high lake inflow when dam breaching activities and lake drawdown would stop. After the dams are breached, fine sediment concentrations would be low and near natural conditions during periods of low flow. Concentrations would be high during progressively higher floodflows as erosion channels widen in the reservoir areas. Within two to five years, concentrations would return to natural levels."

During the 1992 Lower Granite Drawdown Test, suspended sediment concentrations of 3,000 to 9,000 mg/l were measured. Modeling done using HEC-6 produced similar concentrations. Therefore, if the lower Snake River dams were breached, the 3,000 to 9,000 mg/l concentrations would be expected to occur. It is possible for higher concentrations to be found for short time periods as was cited in the 1996 BOR Elwha Report. However, the Elwha dam is a storage project as compared to run-of-the-river projects, so the Elwha dam concentration predictions may not be applicable.

This page is intentionally left blank.

26. Sedimentation Monitoring Before and After Dam Breaching

The following monitoring requirements are foreseen to adequately evaluate erosion and sediment transport if the four lower Snake River dams are breached:

Surveys **Total Cost $1,507,500**

Sediment range resurveys would be required to document the extent and progression of bed and bank erosion during and after the pool drawdown. An initial survey would be required to establish baseline conditions before the start of the drawdown. The initial survey would involve resurveying existing ranges in locations that are subject to frequent change and the establishment of ranges in locations where none presently exist. Immediately following the drawdown of one or more reservoirs, the ranges in the affected pool and the reach extending downstream to the next dam would need to be surveyed. Periodic resurveys would be required until the channel approached a stable condition.

A. Initial survey

1. Establish 32 new ranges in Lower Monumental pool at $1,000 each	$32,000
2. Establish 3 new ranges in McNary Pool	3,000
3. Complete bankline surveys on Little Goose, Ice Harbor 75 ranges at $500 each	37,500
Total	$72,500

B. Post drawdown survey assuming all four pools at once

Resurvey 205 ranges at $1,000 each	$205,000

C. Annual resurvey to be performed each year after the runoff season for 5 years, with a final survey at the end of 10 years. Each survey would extend overbank to range monument.

Resurvey 205 ranges 6 times at $205,000 each	$1,230,000

Sediment Transport **Total Cost $258,780**

Suspended and bedload measurements would be made at the Anatone and Spalding USGS gage sites, downstream of each of the four Snake River dams, and downstream of McNary. The purpose of this effort would be to document the increase in bed load and suspended sediment resulting from the erosion of sediment deposits behind the four Snake River facilities. Sediment transport would be measured downstream of the pool to be lowered and below each downstream facility immediately prior to the beginning of the drawdown. This will establish a baseline condition for the drawdown period. Sediment transport would then be measured once each day during the drawdown process and for 30 days following complete evacuation of the pool. During the following spring runoff period, sediment transport measurements would be made at 15-day intervals from 15 April through 30 July downstream of each of the five facilities and at the Anatone and Spalding gage sites. During the next 4 years and again after 10 years, suspended and bedload measurements would be measured

near the peak of the runoff period. These latter measurements would be made at three locations: 1) the Anatone gage site, 2) the Spalding gage site, and 3) just downstream of Ice Harbor Dam.

Estimated Costs:

A. Pre-drawdown sediment transport measurements	
Measurements at 7 locations on same day	
Assume two boat crews 3 days each at 1500/day:	$9,000
(Probably a bit high, since one crew may work out of Tri-Cities USGS office)	
Lab at 90/sample (bed load and suspended)	630
B. Drawdown sediment transport measurements	
Assume two boat crews 60 days each:	$180,000
Lab at 90/sample	37,800
C. Annual sediment transport measurements	
Assume two boat crews, total of 4 days each measurement	
Five events at $6000 each	$30,000
Lab at 90/sample	1,350

Sediment Gradation **Total Cost $80,000**

Sediment sampling before and after the drawdown would provide a means of determining how the various sizes were moving downstream, how fast the river was cleaning sediment from the original channel bed, and how the substrate was changing in Lake Wallula as a result of the drawdown. If all of the dams were to be breached simultaneously, it is likely that the transport capacity of the flow will be exceeded for a time. Under these conditions the upper reaches of the river would erode down to the original cobble layer first. Progressively, more of the river would be swept clean in a downstream direction as the sediment is swept along by the current.

The effort could be as simple as following the upstream edge of the sediment downstream by a single boat crew operating continuously on the river, keeping records on the approximate location of the upstream edge of the sediment layer as it washed downstream, or it could involve sediment sampling which would include the depositional area in Lake Wallula.

Aerial Photography **Total Cost $62,400**

Fly river before drawdown, immediately after drawdown, once each year for 5 years and again at 10 years after drawdown. Cost per flight is about $7,800.

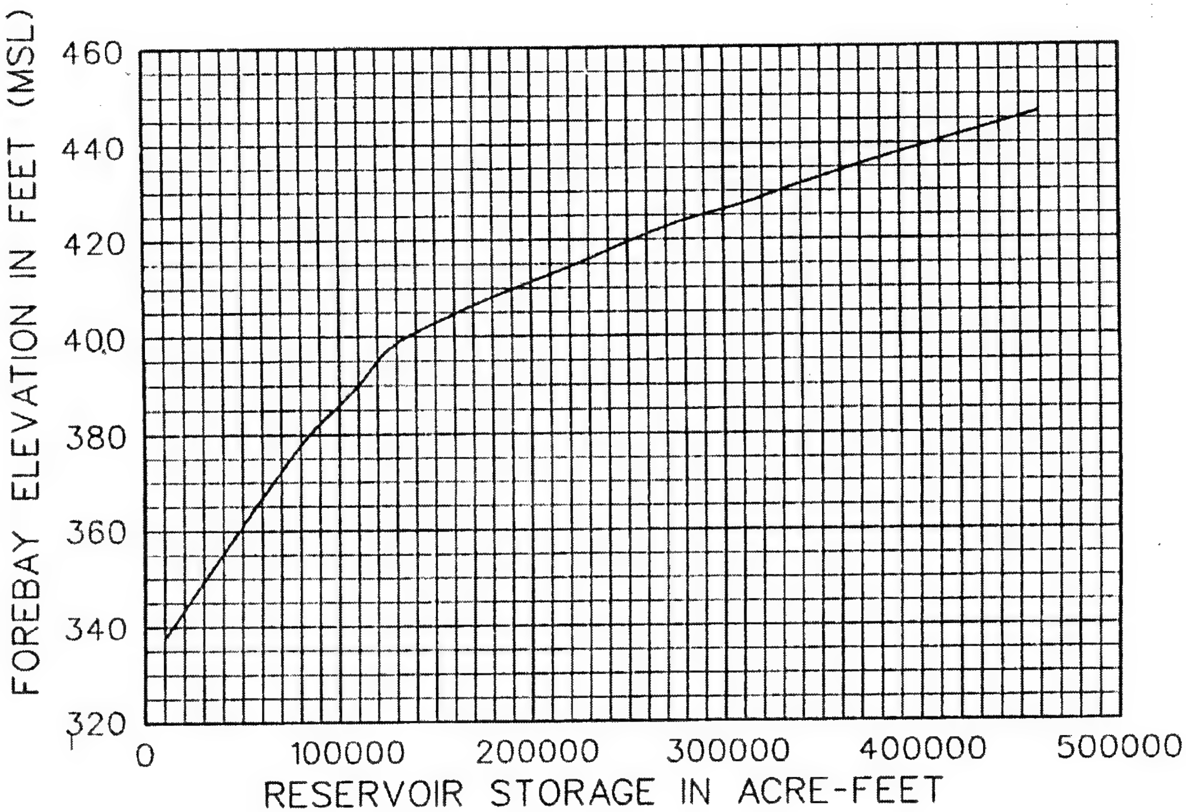
Data Analysis and Reporting **Total Cost $250,000**

Analyze the collected data and write one or more reports explaining the results of the monitoring.

SEDIMENT MONITORING ESTIMATED TOTAL COST: $2,158,680

27. Lower Snake River Project Storage Curves

Charts 27-1 through 27-4 present relations between project forebay elevations and reservoir storages for Ice Harbor, Lower Monumental, Little Goose, and Lower Granite facilities. These charts are all based on a lower Snake River discharge of 1,416 m^3/second (50,000 cfs), the approximate mean daily discharge of the lower Snake River.



NOTES:

1. RESERVOIR CAPACITY IS A FUNCTION OF BOTH POOL ELEVATION AND DISCHARGE. THIS CURVE IS BASED ON A DISCHARGE OF 50,000 CUBIC FEET PER SECOND.
2. ELEVATION STORAGE VALUES WERE COMPUTED USING U. S. ARMY CORPS OF ENGINEERS SOUNDINGS (DATED JUNE 10, 1935) AND 10-FOOT CONTOUR INTERVAL MAPS (BASED ON 1956 AERIAL PHOTOGRAPHY.)

DATE	REVISION	BY

SNAKE RIVER BASIN
SYSTEM CONFIGURATION STUDY
ICE HARBOR RESERVOIR

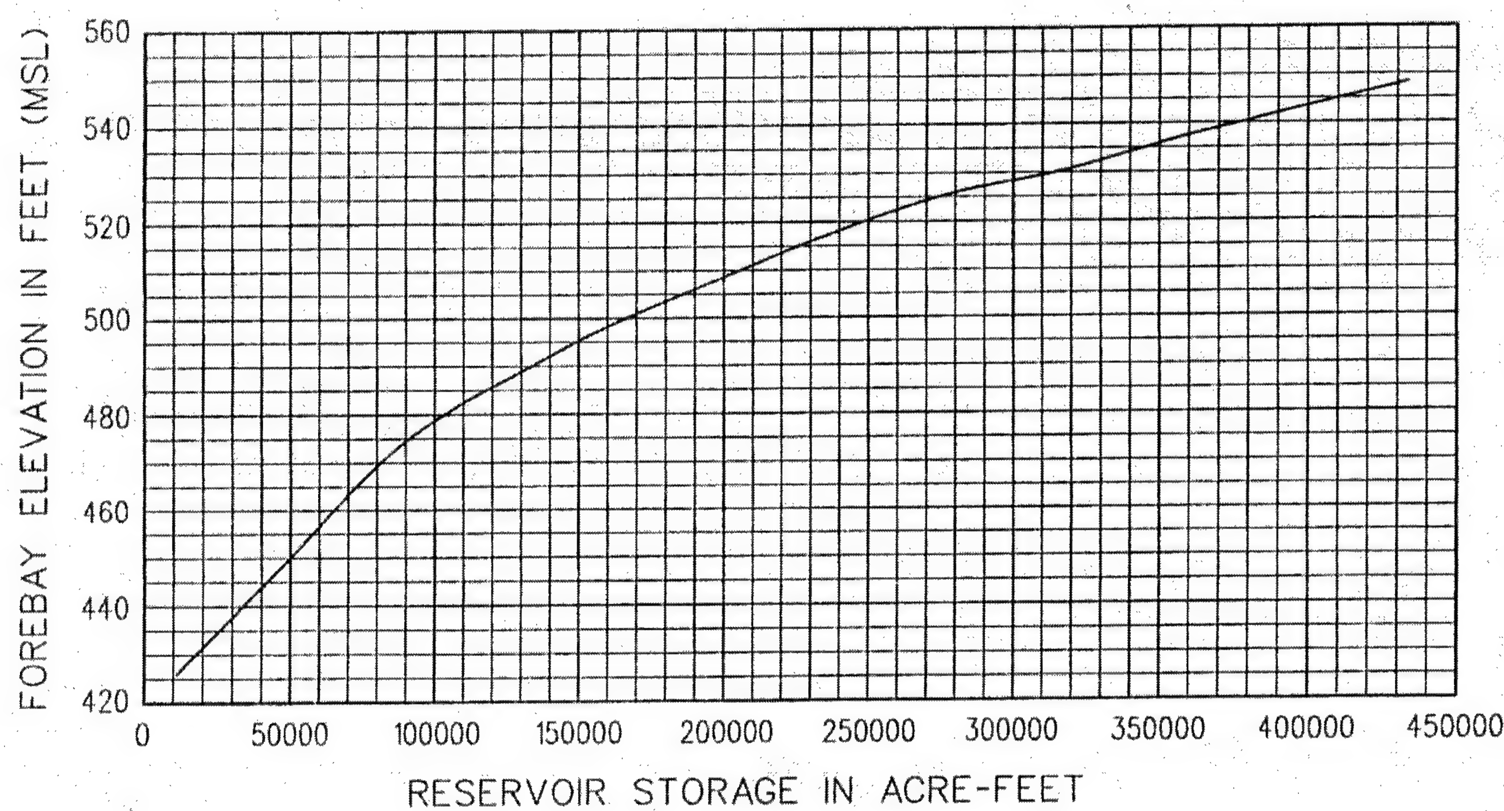
FOREBAY ELEVATION VERSUS RESERVOIR STORAGE

U. S. ARMY ENGINEER DISTRICT
WALLA WALLA - HYDROLOGY BRANCH

DESIGNED	DRAWN	DATE
MAXSON	SCHUSTER	15 OCT 1992

A00197

Chart 27-1.



NOTES:

1. RESERVOIR CAPACITY IS A FUNCTION OF BOTH POOL ELEVATION AND DISCHARGE. THIS CURVE IS BASED ON A DISCHARGE OF 50,000 CUBIC FEET PER SECOND.
2. ELEVATION STORAGE VALUES WERE COMPUTED USING U. S. ARMY CORPS OF ENGINEERS SOUNDINGS (DATED JUNE 10, 1935) AND 10-FOOT CONTOUR INTERVAL MAPS (BASED ON 1956 AERIAL PHOTOGRAPHY.)

DATE	REVISION	BY

SNAKE RIVER BASIN
SYSTEM CONFIGURATION STUDY
LOWER MONUMENTAL RESERVOIR

FOREBAY ELEVATION
VERSUS
RESERVOIR STORAGE

U. S. ARMY ENGINEER DISTRICT
WALLA WALLA - HYDROLOGY BRANCH

DESIGNED	DRAWN	DATE
MAXSON	SCHUSTER	14 OCT 1992

A00195

Chart 27-2.

SNAKE RIVER BASIN
SYSTEM CONFIGURATION STUDY
LITTLE GOOSE RESERVOIR

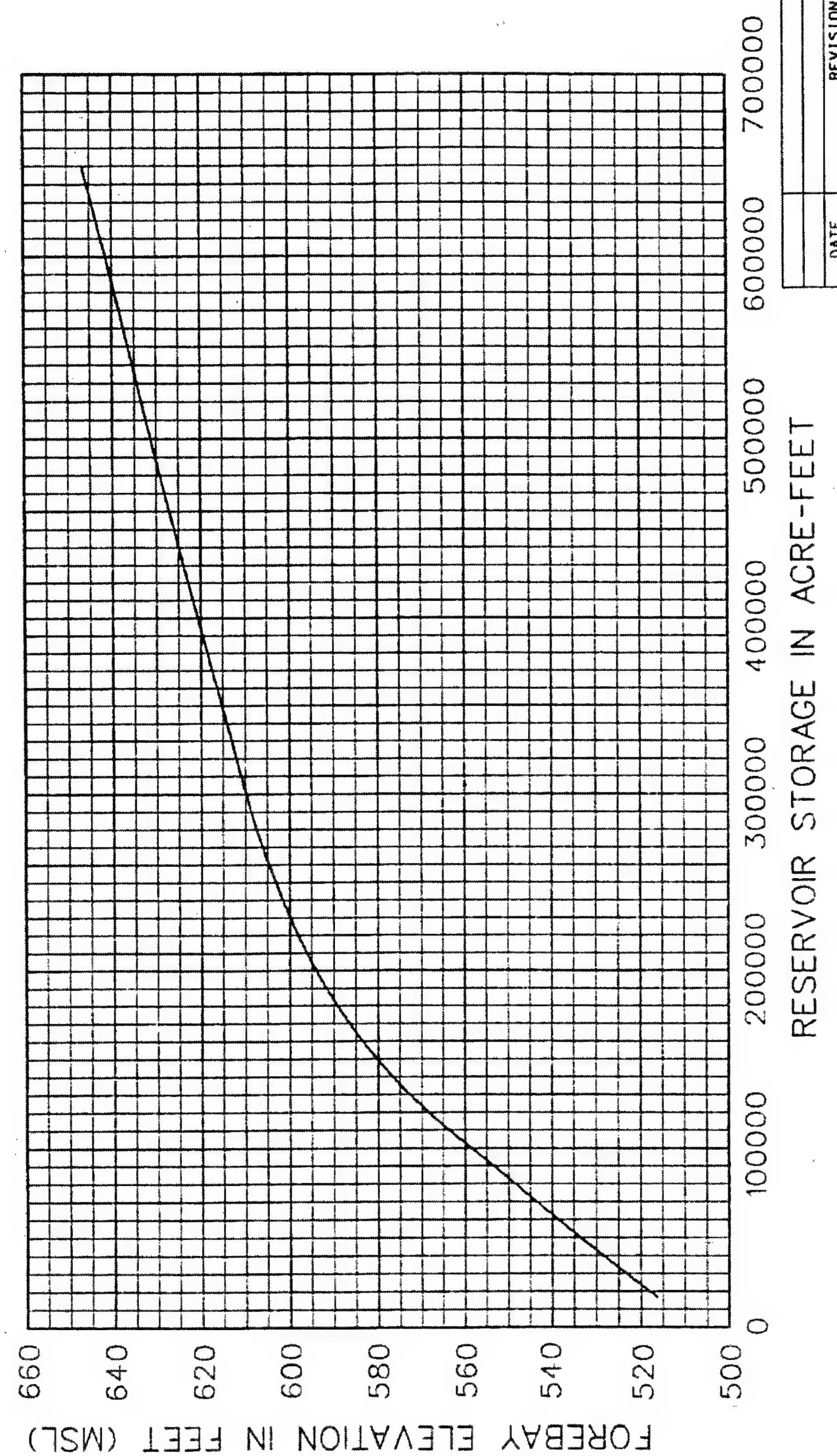
FOREBAY ELEVATION VERSUS RESERVOIR STORAGE

U. S. ARMY ENGINEER DISTRICT
WALLA WALLA - HYDROLOGY BRANCH

DESIGNED	DRAWN	DATE
MAXSON	SCHUSTER	15 OCT 1992

DATE	REVISION	BY

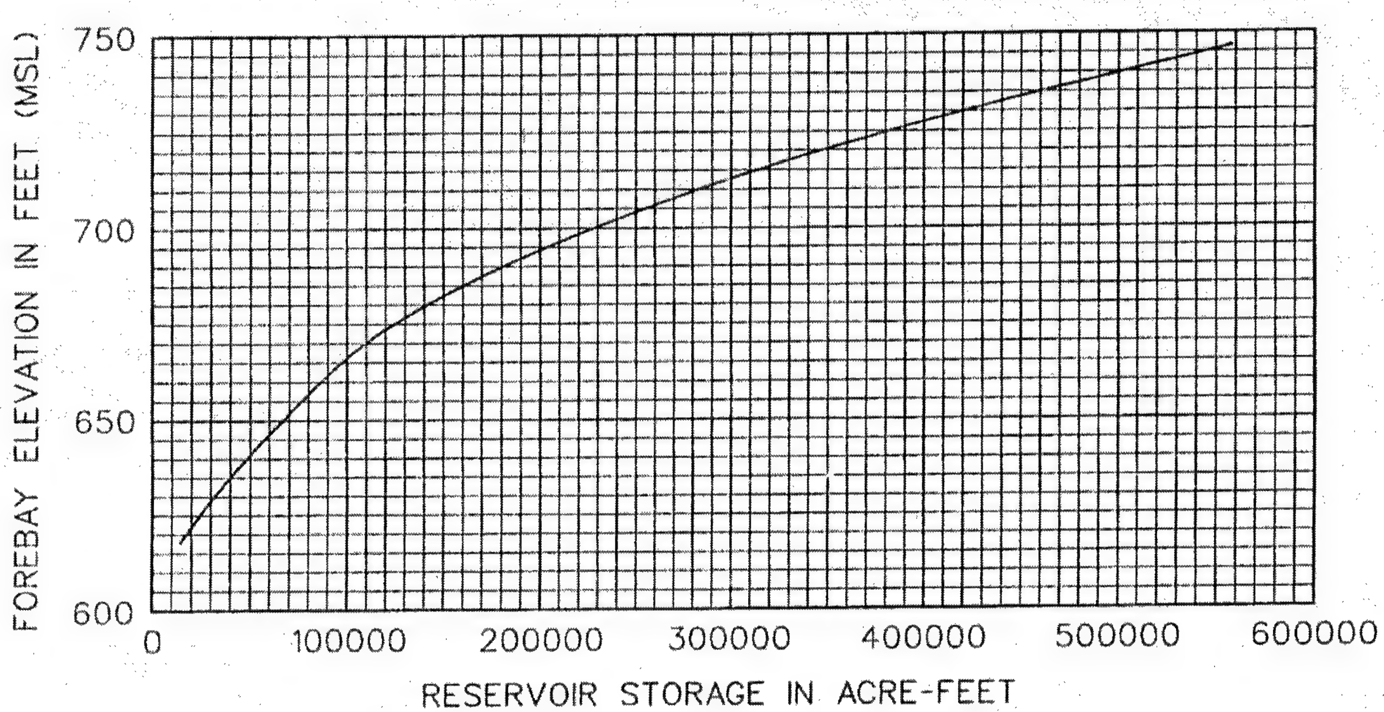
A00196



NOTES:

1. RESERVOIR CAPACITY IS A FUNCTION OF BOTH POOL ELEVATION AND DISCHARGE. THIS CURVE IS BASED ON A DISCHARGE OF 50,000 CUBIC FEET PER SECOND.
2. ELEVATION STORAGE VALUES WERE COMPUTED USING U. S. ARMY CORPS OF ENGINEERS SOUNDINGS (DATED JUNE 10, 1935) AND 10-FOOT CONTOUR INTERVAL MAPS (BASED ON 1956 AERIAL PHOTOGRAPHY.)

Chart 27-3.



NOTES:

1. RESERVOIR CAPACITY IS A FUNCTION OF BOTH POOL ELEVATION AND DISCHARGE. THIS CURVE IS BASED ON A DISCHARGE OF 50,000 CUBIC FEET PER SECOND.
2. ELEVATION STORAGE VALUES WERE COMPUTED USING U. S. ARMY CORPS OF ENGINEERS SOUNDINGS (DATED JUNE 10, 1935) AND 10-FOOT CONTOUR INTERVAL MAPS (BASED ON 1956 AERIAL PHOTOGRAPHY.)

DATE	REVISION	BY

SNAKE RIVER BASIN
SYSTEM CONFIGURATION STUDY
LOWER GRANITE RESERVOIR

FOREBAY ELEVATION VERSUS RESERVOIR STORAGE

U. S. ARMY ENGINEER DISTRICT
WALLA WALLA - HYDROLOGY BRANCH

DESIGNED	DRAWN	DATE
MAXSON	SCHUSTER	14 OCT 1992

A00194

Chart 27-4.

This page is intentionally left blank.

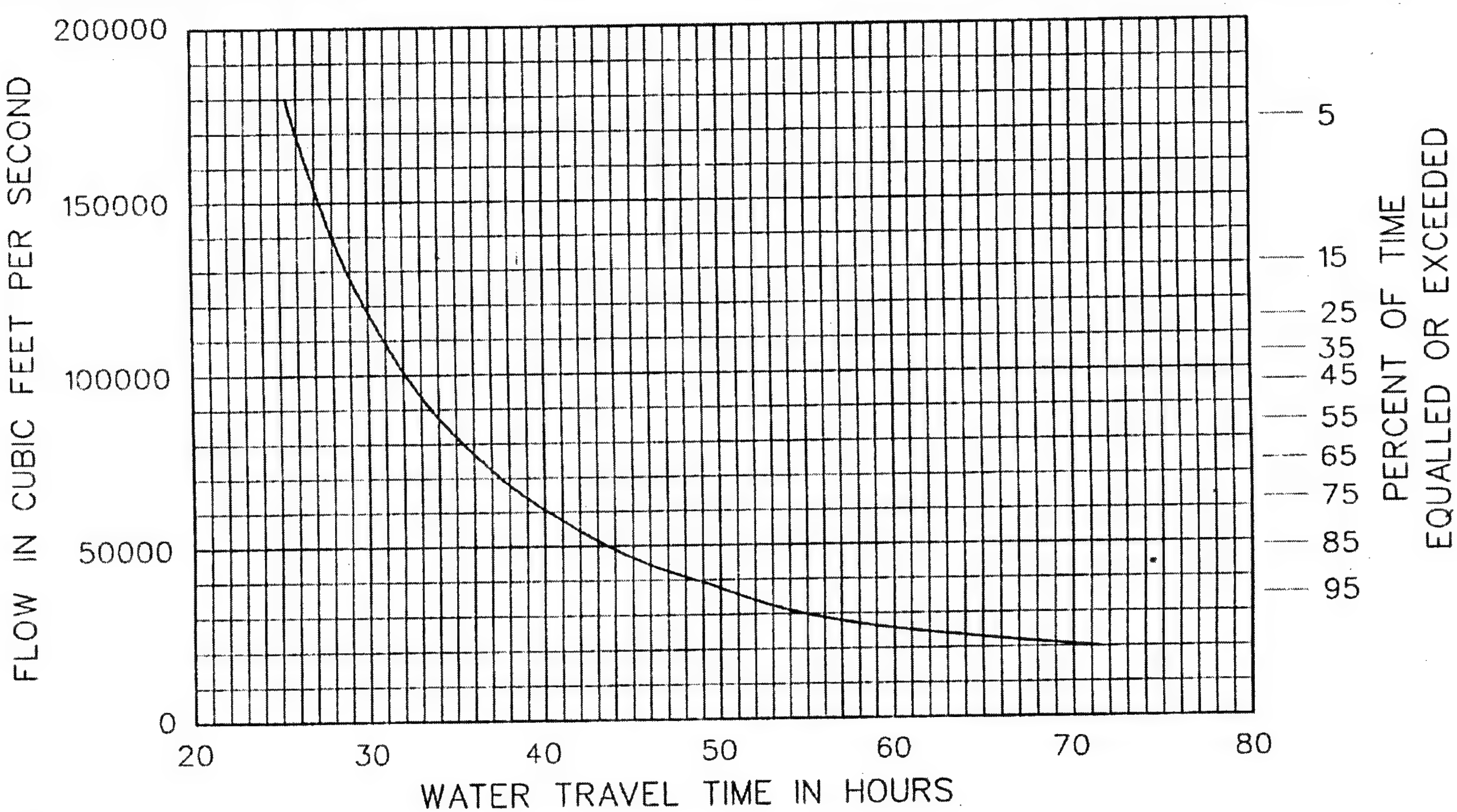
28. Flood Control Transfers

The four lower Snake River facilities are not presently operated to provide any flood control and therefore, dam breaching would not modify the existing flood control capabilities within the Snake River system. However, breaching would eliminate any potential to use their reservoir space for system flood control purposes, since no means would be available to pond the water and use this under controlled conditions. Since the four lower Snake River facilities are all classified as run-of-river projects, their available storage is minimal when compared to projects designed to provide some degree of flood control. Based on Charts 27-1 through 27-4, the total gross storage space available in the four lower Snake River facilities is approximately 222,120 hectare-meters (1,800,000 acre-feet). Of this storage space, approximately 154,250 hectare-meters (1,250,000 acre-feet) occurs between the project spillway crests and the normal pool elevations.

This page is intentionally left blank.

29. Lower Snake River Water Travel Times

Charts 29-1 through 29-6 present lower Snake River water travel times between the Clearwater River and the Columbia River for several lower Snake River facility pool conditions, ranging from natural free flow to normal full pool. Reservoir drawdown will create reaches of free-flowing river between each dam and the next downstream pool, with greater lengths of free-flowing reaches being created by greater amounts of drawdown. The average water velocity through each reservoir will increase. However, it is important to note that each alternative except the dam breaching option maintains a large pool, and that water velocities are not substantially changed through the pools. The increase in the average velocity of the reservoir is most affected by the substantial increase in the free-flowing reach. The drawdown alternatives result in a substantial decrease in average water travel time, based on mathematical modeling using the Corps HEC-2 model (Water Surface Profiles). This was confirmed by measurements taken during the 1992 drawdown test. The dam breaching option results in the greatest decrease in water travel time, essentially returning the river in this reach to almost a near-natural state. The average water travel time ranges from 8 to 18 percent of what it would be at normal pool elevation for flows from 708 m^3/second to 4,531 m^3/second (25,000 cfs to 160,000 cfs).



NOTES:

1. TRAVEL TIMES ON THIS CURVE WERE COMPUTED USING THE HYDROLOGIC ENGINEERING CENTER PROGRAM "WATER SURFACE PROFILES." (HEC-2). CROSS SECTIONS USED IN THE MODEL WERE DEVELOPED FROM TWO SOURCES: 1) SEDIMENT RANGE DATA FROM RIVER MILE 107.4 (LOWER GRANITE DAM) TO THE SNAKE-CLEARWATER RIVER CONFLUENCE AND 2) 1934 SOUNDING DATA AND TOPOGRAPHIC MAPPING FOR THE REACH BETWEEN COLUMBIA-SNAKE RIVER CONFLUENCE TO LOWER GRANITE DAM.

2. THIS ALTERNATIVE IS FOR ACHIEVING NEAR FREE FLOW CONDITIONS.

3. DURATION PERCENTAGES WERE COMPUTED FOR LOWER GRANITE INFLOWS FOR 15 APRIL TO 15 JUNE FOR THE PERIOD 1976 THROUGH 1992.

SNAKE RIVER BASIN
SYSTEM CONFIGURATION STUDY
SNAKE RIVER FROM COLUMBIA RIVER CONFLUENCE TO CLEARWATER RIVER CONFLUENCE

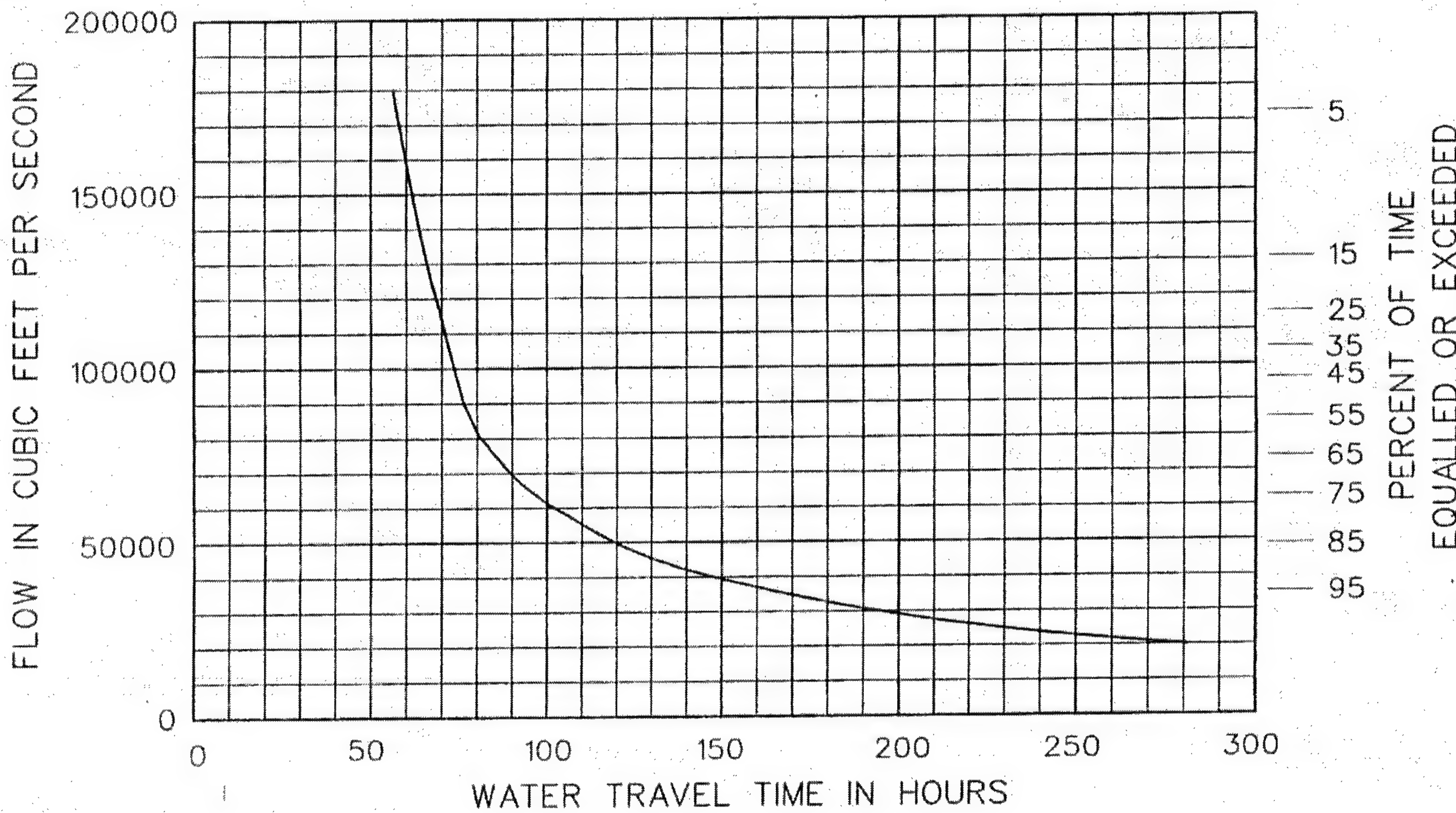
WATER TRAVEL TIME NEAR FREE FLOW

U. S. ARMY ENGINEER DISTRICT
WALLA WALLA - HYDROLOGY BRANCH

DESIGNED	DRAWN	DATE
MAXSON	SCHUSTER	21 AUG 1992

A00183

Chart 29-1.



NOTES:

1. TRAVEL TIMES ON THIS CURVE WERE COMPUTED USING THE HYDROLOGIC ENGINEERING CENTER PROGRAM "WATER SURFACE PROFILES," (HEC-2). CROSS SECTIONS USED IN THE MODEL WERE DEVELOPED FROM TWO SOURCES; 1) SEDIMENT RANGE DATA FROM RIVER MILE 107.4 (LOWER GRANITE DAM) TO THE SNAKE-CLEARWATER RIVER CONFLUENCE AND 2) 1934 SOUNDING DATA AND TOPOGRAPHIC MAPPING FOR THE REACH BETWEEN COLUMBIA-SNAKE RIVER CONFLUENCE TO LOWER GRANITE DAM.

2. WATER SURFACE ELEVATIONS ARE TO REMAIN AT THE EXISTING SPILLWAY CRESTS WHICH ARE 391, 483, 581, AND 681 FEET MSL FOR ICE HARBOR, LOWER MONUMENTAL, LITTLE GOOSE AND LOWER GRANITE, RESPECTIVELY.

3. DURATION PERCENTAGES WERE COMPUTED FOR LOWER GRANITE INFLOWS FOR 15 APRIL TO 15 JUNE FOR THE PERIOD 1976 THROUGH 1992.

A00184

SNAKE RIVER BASIN
SYSTEM CONFIGURATION STUDY
SNAKE RIVER FROM COLUMBIA RIVER CONFLUENCE TO CLEARWATER RIVER CONFLUENCE

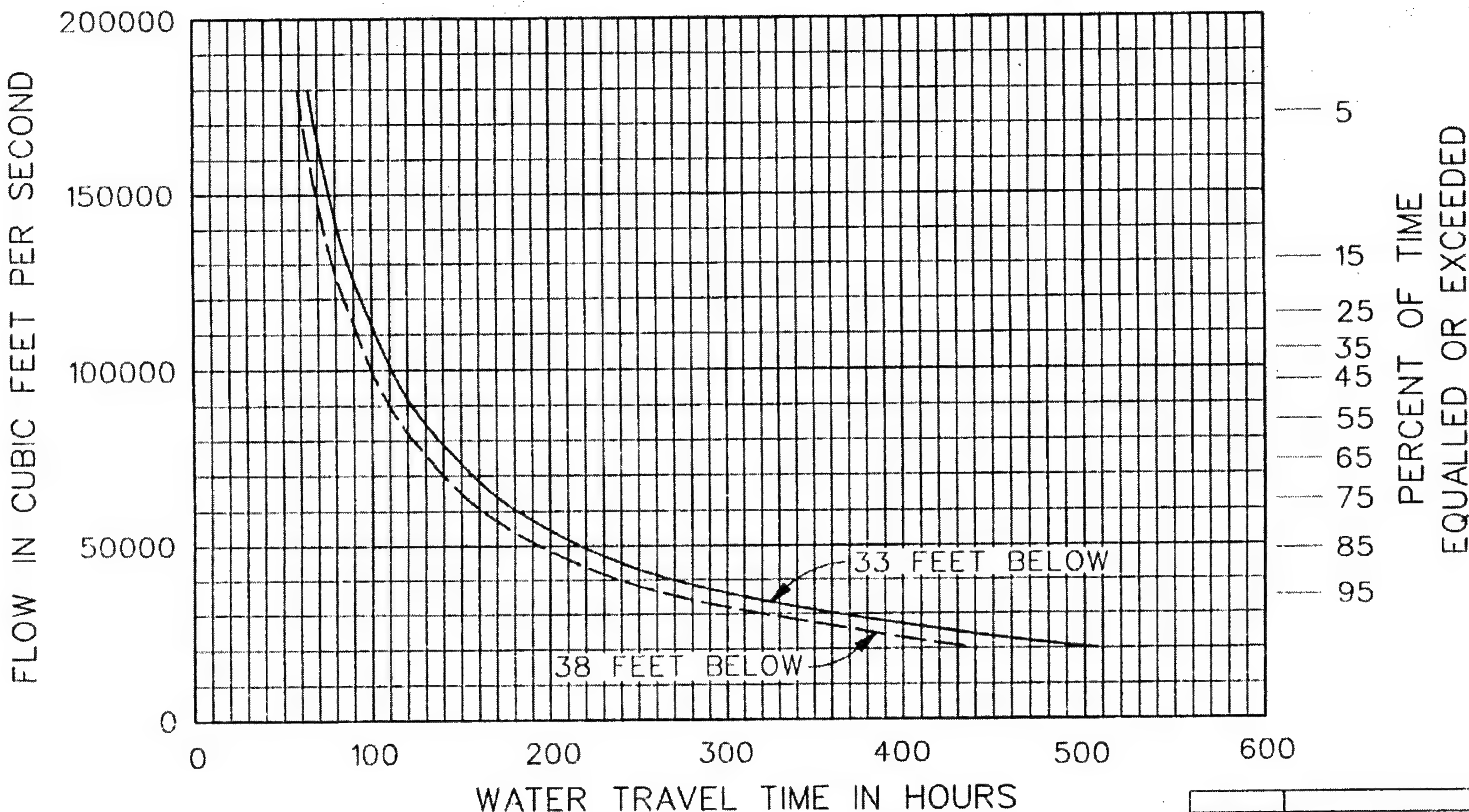
WATER TRAVEL TIME

SPILLWAY CREST

U. S. ARMY ENGINEER DISTRICT
WALLA WALLA - HYDROLOGY BRANCH

DESIGNED	DRAWN	DATE
MAXSON	SCHUSTER	21 AUG 1992

Chart 29-2.



NOTES:

1. THESE CURVES WERE COMPUTED USING THE HYDROLOGIC ENGINEERING CENTER PROGRAM "WATER SURFACE PROFILES." (HEC-2). CROSS SECTIONS USED IN THE MODEL WERE DEVELOPED FROM TWO SOURCES: 1) SEDIMENT RANGE DATA FROM RIVER MILE 107.4 (LOWER GRANITE DAM) TO THE SNAKE-CLEARWATER RIVER CONFLUENCE AND 2) 1934 SOUNDING DATA AND TOPOGRAPHIC MAPPING FOR THE REACH BETWEEN THE COLUMBIA-SNAKE RIVER CONFLUENCE AND LOWER GRANITE DAM.

2. THIS ALTERNATIVE DRAWS DOWN LOWER MONUMENTAL, LITTLE GOOSE AND LOWER GRANITE RESERVOIRS 33 (38) FEET TO ELEVATIONS 507 (502), 605 (600), AND 705 (700) FEET MSL, RESPECTIVELY, AND ICE HARBOR RESERVOIR 25 FEET TO ELEVATION 415 FEET MSL.

3. DURATION PERCENTAGES WERE COMPUTED FOR LOWER GRANITE INFLOWS FOR 15 APRIL TO 15 JUNE FOR THE PERIOD 1976 THROUGH 1992.

DATE	REVISION	BY

SNAKE RIVER BASIN
SYSTEM CONFIGURATION STUDY
SNAKE RIVER FROM COLUMBIA RIVER CONFLUENCE TO CLEARWATER RIVER CONFLUENCE

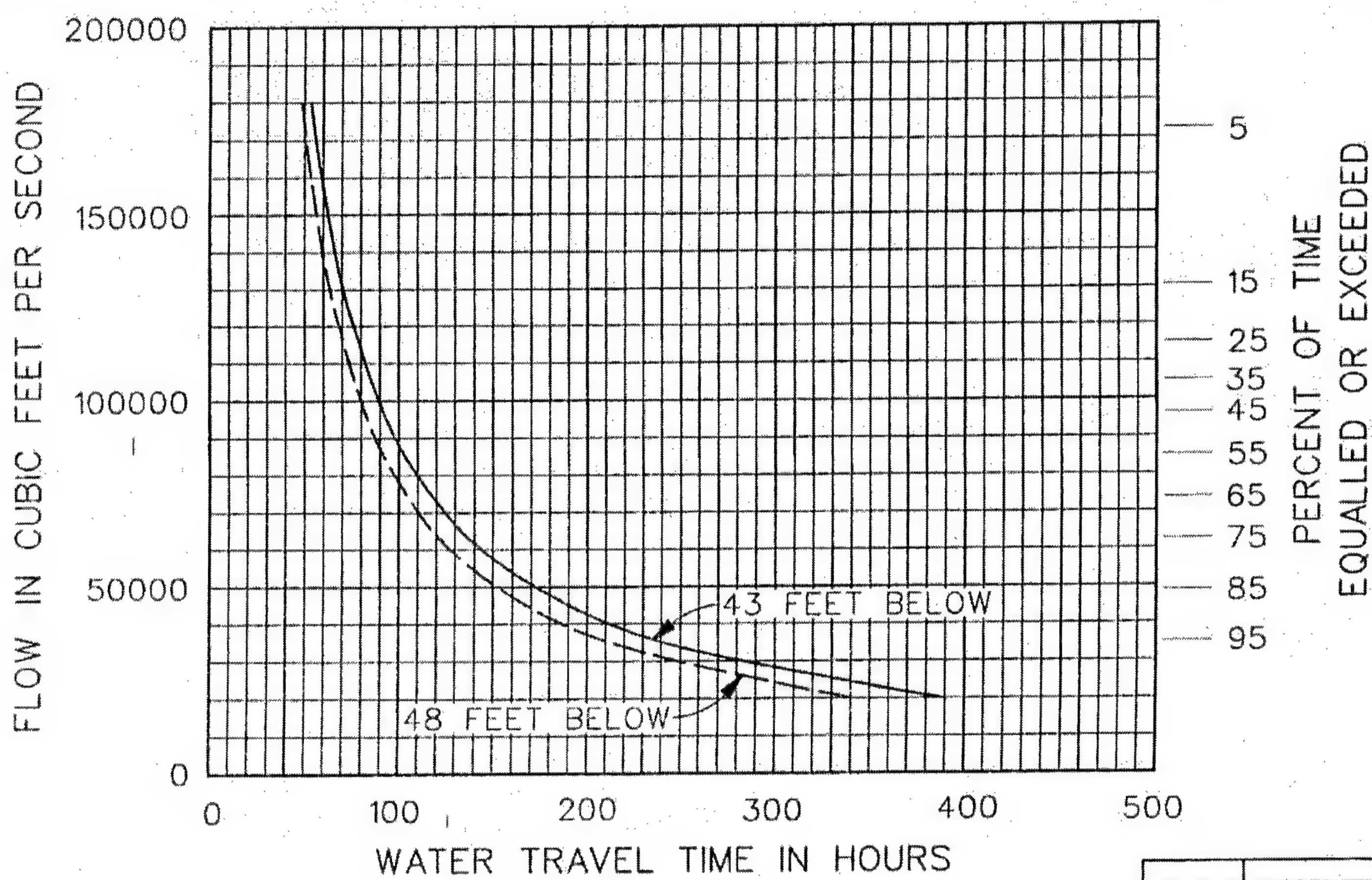
WATER TRAVEL TIME
33 & 38 FEET BELOW
NORMAL FULL POOL
ELEVATION

U. S. ARMY ENGINEER DISTRICT
WALLA WALLA - HYDROLOGY BRANCH

DESIGNED	DRAWN	DATE
MAXSON	SCHUSTER	21 AUG 1992

A00185

Chart 29-3.



NOTES:

1. THESE CURVES WERE COMPUTED USING THE HYDROLOGIC ENGINEERING CENTER PROGRAM "WATER SURFACE PROFILES," (HEC-2). CROSS SECTIONS USED IN THE MODEL WERE DEVELOPED FROM TWO SOURCES: 1) SEDIMENT RANGE DATA FROM RIVER MILE 107.4 (LOWER GRANITE DAM) TO THE SNAKE-CLEARWATER RIVER CONFLUENCE AND 2) 1934 SOUNDING DATA AND TOPOGRAPHIC MAPPING FOR THE REACH BETWEEN THE COLUMBIA-SNAKE RIVER CONFLUENCE AND LOWER GRANITE DAM.

2. THIS ALTERNATIVE DRAWS DOWN LOWER MONUMENTAL, LITTLE GOOSE, AND LOWER GRANITE RESERVOIRS 43 (48) FEET TO ELEVATIONS 497 (492), 595 (590), AND 695 (690) FEET MSL, RESPECTIVELY, AND ICE HARBOR RESERVOIR 35 FEET TO ELEVATION 405 FEET MSL.

3. DURATION PERCENTAGES WERE COMPUTED FOR LOWER GRANITE INFLOWS FOR 15 APRIL TO 15 JUNE FOR THE PERIOD 1976 THROUGH 1992.

A00186

DATE	REVISION	BY

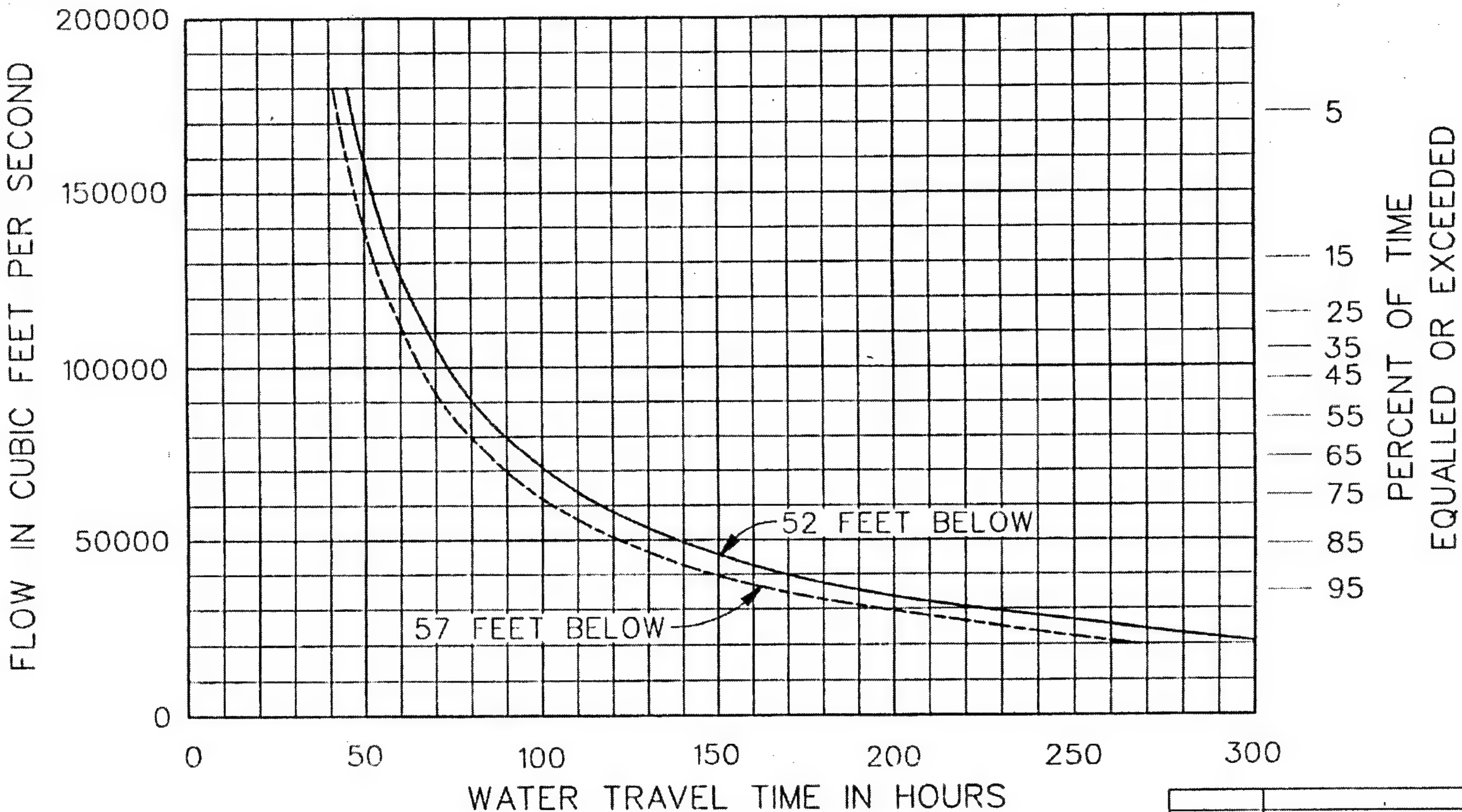
SNAKE RIVER BASIN
SYSTEM CONFIGURATION STUDY
SNAKE RIVER FROM COLUMBIA RIVER CONFLUENCE TO CLEARWATER RIVER CONFLUENCE

WATER TRAVEL TIME
43 & 48 FEET BELOW
NORMAL FULL POOL
ELEVATION

U. S. ARMY ENGINEER DISTRICT
WALLA WALLA - HYDROLOGY BRANCH

DESIGNED	DRAWN	DATE
MAXSON	SCHUSTER	25 AUG 1992

Chart 29-4.



NOTES:

1. THESE CURVES WERE COMPUTED USING THE HYDROLOGIC ENGINEERING CENTER PROGRAM "WATER SURFACE PROFILES," (HEC-2). CROSS SECTIONS USED IN THE MODEL WERE DEVELOPED FROM TWO SOURCES: 1) SEDIMENT RANGE DATA FROM RIVER MILE 107.4 (LOWER GRANITE DAM) TO THE SNAKE-CLEARWATER RIVER CONFLUENCE AND 2) 1934 SOUNDING DATA AND TOPOGRAPHIC MAPPING FOR THE REACH BETWEEN THE COLUMBIA-SNAKE RIVER CONFLUENCE AND LOWER GRANITE DAM.

2. THIS ALTERNATIVE DRAWS DOWN LOWER MONUMENTAL, LITTLE GOOSE, AND LOWER GRANITE RESERVOIRS 52 (57) FEET TO ELEVATIONS 488 (483), 586 (581), AND 686 (681) FEET MSL, RESPECTIVELY, AND ICE HARBOR RESERVOIR 43 FEET TO ELEVATION 397 FEET MSL.

3. DURATION PERCENTAGES WERE COMPUTED FOR LOWER GRANITE INFLOWS FOR 15 APRIL TO 15 JUNE FOR THE PERIOD 1976 THROUGH 1992.

A00187

DATE	REVISION	BY

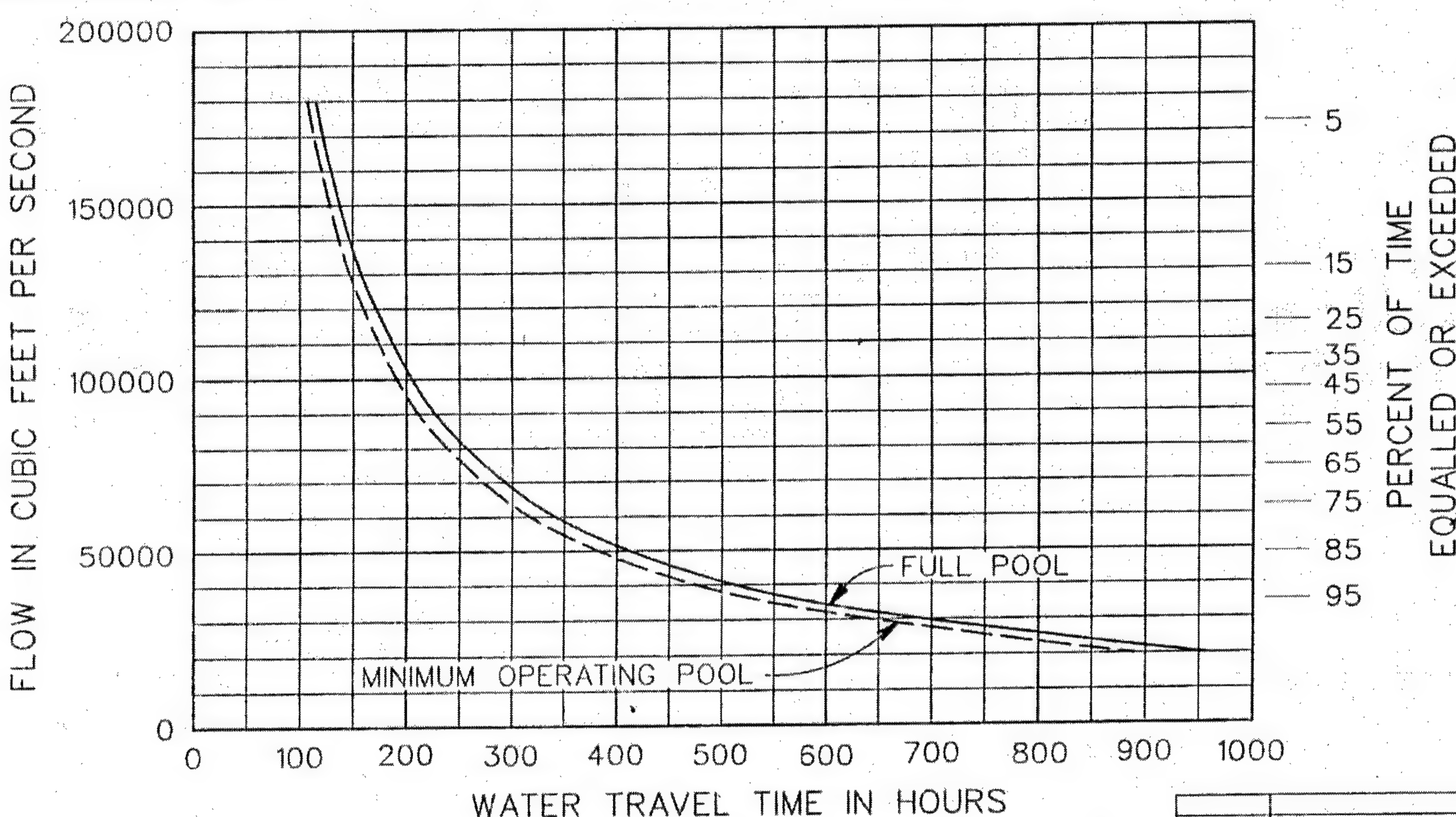
SNAKE RIVER BASIN
SYSTEM CONFIGURATION STUDY
SNAKE RIVER FROM COLUMBIA RIVER CONFLUENCE TO CLEARWATER RIVER CONFLUENCE

WATER TRAVEL TIME 52 & 57 FEET BELOW NORMAL FULL POOL ELEVATION

U. S. ARMY ENGINEER DISTRICT
WALLA WALLA - HYDROLOGY BRANCH

DESIGNED	DRAWN	DATE
MAXSON	SCHUSTER	21 AUG 1992

Chart 29-5.



NOTES:

1. THESE CURVES WERE COMPUTED USING THE HYDROLOGIC ENGINEERING CENTER PROGRAM "WATER SURFACE PROFILES," (HEC-2). CROSS SECTIONS USED IN THE MODEL WERE DEVELOPED FROM TWO SOURCES: 1) SEDIMENT RANGE DATA FROM RIVER MILE 107.4 (LOWER GRANITE DAM) TO THE SNAKE-CLEARWATER RIVER CONFLUENCE AND 2) 1934 SOUNDING DATA AND TOPOGRAPHIC MAPPING FOR THE REACH BETWEEN THE COLUMBIA-SNAKE RIVER CONFLUENCE AND LOWER GRANITE DAM.

2. DURATION PERCENTAGES WERE COMPUTED FOR LOWER GRANITE INFLOWS FOR 15 APRIL TO 15 JUNE FOR THE PERIOD 1976 THROUGH 1992.

DATE	REVISION	BY

SNAKE RIVER BASIN
SYSTEM CONFIGURATION STUDY
SNAKE RIVER FROM COLUMBIA RIVER CONFLUENCE TO CLEARWATER RIVER CONFLUENCE

WATER TRAVEL TIME
FULL POOL / MINIMUM
POOL ELEVATIONS

U. S. ARMY ENGINEER DISTRICT
WALLA WALLA - HYDROLOGY BRANCH

DESIGNED	DRAWN	DATE
MAXSON	SCHUSTER	8 OCT 1992

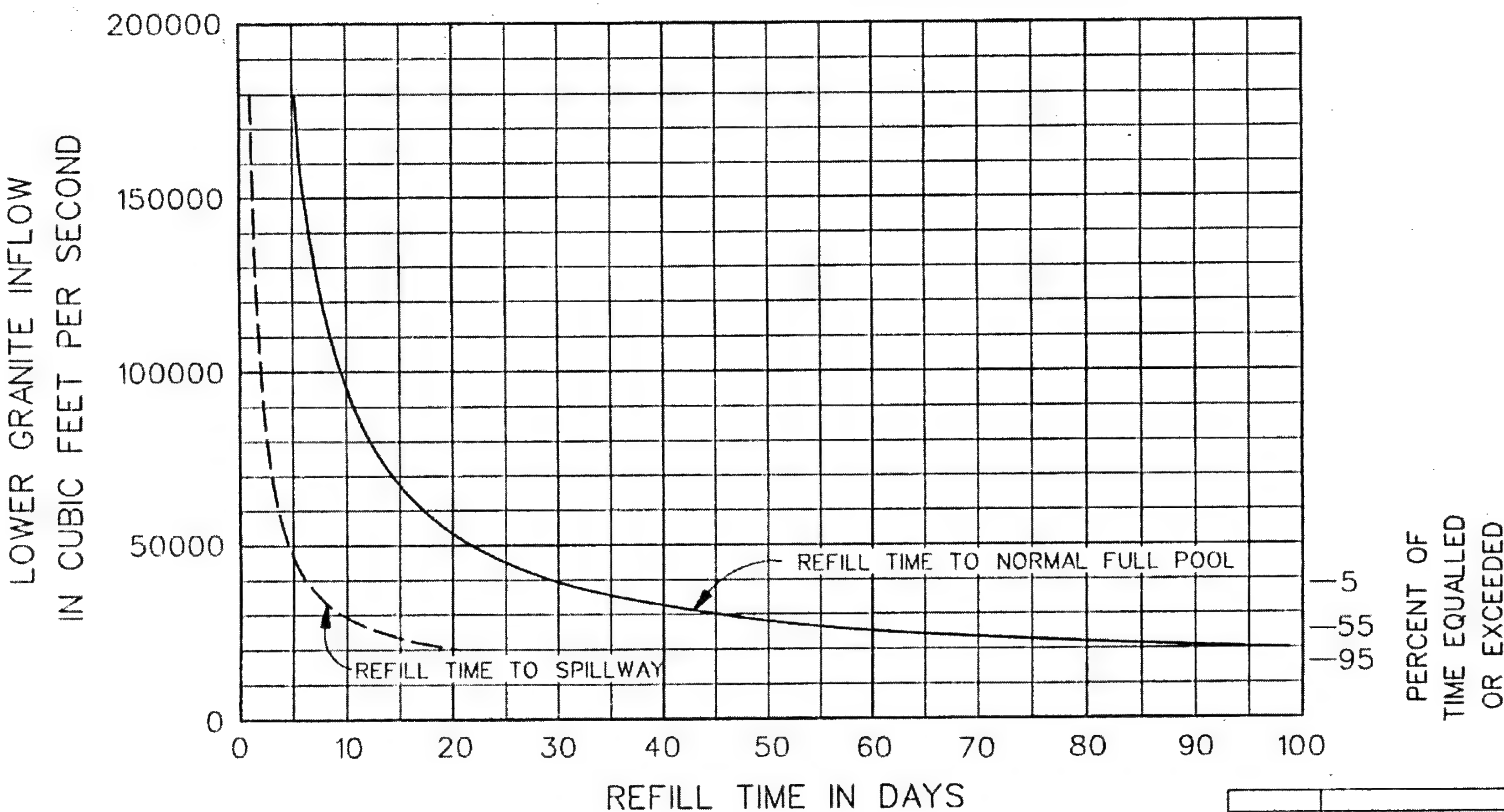
A00188

Chart 29-6.

This page is intentionally left blank.

30. Lower Snake River Refill Times

Charts 30-1 through 30-5 present reservoir refill times required to refill the four lower Snake River reservoirs for conditions ranging from near natural freeflow conditions up to drawdown to the project spillway crest elevations.



NOTES:

1. THIS CURVE DEPICTS THE TIME TO REFILL THE FOUR LOWER SNAKE RIVER PROJECTS FROM EXISTING SPILLWAY CRESTS OF 391, 438, 581, AND 681 FEET MSL FOR ICE HARBOR, LOWER MONUMENTAL, LITTLE GOOSE, AND LOWER GRANITE, RESPECTIVELY, TO NORMAL FULL POOL. THE ORDER OF REFILL IS NOT CONSIDERED.
2. A MINIMUM PROJECT RELEASE OF 11,000 CUBIC FEET PER SECOND IS CONSIDERED IN THE REFILL TIMES.
3. DURATION PERCENTAGES WERE COMPUTED FOR LOWER GRANITE INFLOWS FOR 1 SEPTEMBER THROUGH 31 OCTOBER FOR THE PERIOD 1976 THROUGH 1992.

DATE	REVISION	BY

SNAKE RIVER BASIN
SYSTEM CONFIGURATION STUDY
ICE HARBOR, LOWER MONUMENTAL, LITTLE GOOSE, AND LOWER GRANITE RESERVOIRS

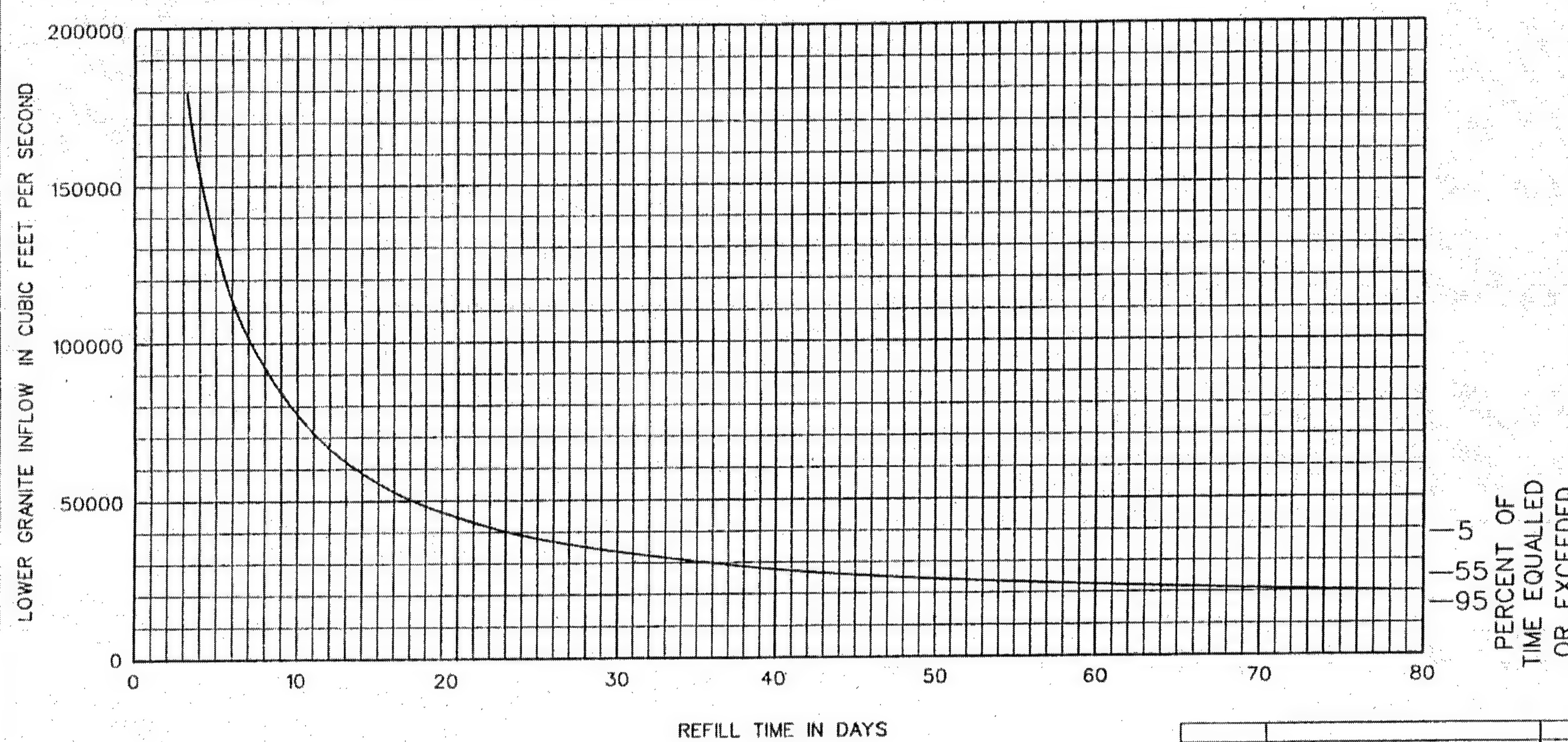
REFILL TIME FROM NEAR NATURAL CONDITION TO NORMAL FULL POOL ELEVATION

U. S. ARMY ENGINEER DISTRICT
WALLA WALLA - HYDROLOGY BRANCH

DESIGNED	DRAWN	DATE
MAXSON	SCHUSTER	13 OCT 1992

A00193

Chart 30-1.



NOTES:

1. THIS CURVE DEPICTS THE TIME TO REFILL THE FOUR LOWER SNAKE RIVER PROJECTS FROM EXISTING SPILLWAY CRESTS OF 391, 438, 581, AND 681 FEET MSL FOR ICE HARBOR, LOWER MONUMENTAL, LITTLE GOOSE, AND LOWER GRANITE, RESPECTIVELY TO NORMAL FULL POOL. THE ORDER OF REFILL IS NOT CONSIDERED.
2. A MINIMUM PROJECT RELEASE OF 11,000 CUBIC FEET PER SECOND IS CONSIDERED IN THE REFILL TIMES.
3. DURATION PERCENTAGES WERE COMPUTED FOR LOWER GRANITE INFLOWS FOR 1 SEPTEMBER THROUGH 31 OCTOBER FOR THE PERIOD 1976 THROUGH 1992.

DATE	REVISION	BY

SNAKE RIVER BASIN
SYSTEM CONFIGURATION STUDY
ICE HARBOR, LOWER MONUMENTAL, LITTLE GOOSE, AND LOWER GRANITE RESERVOIRS

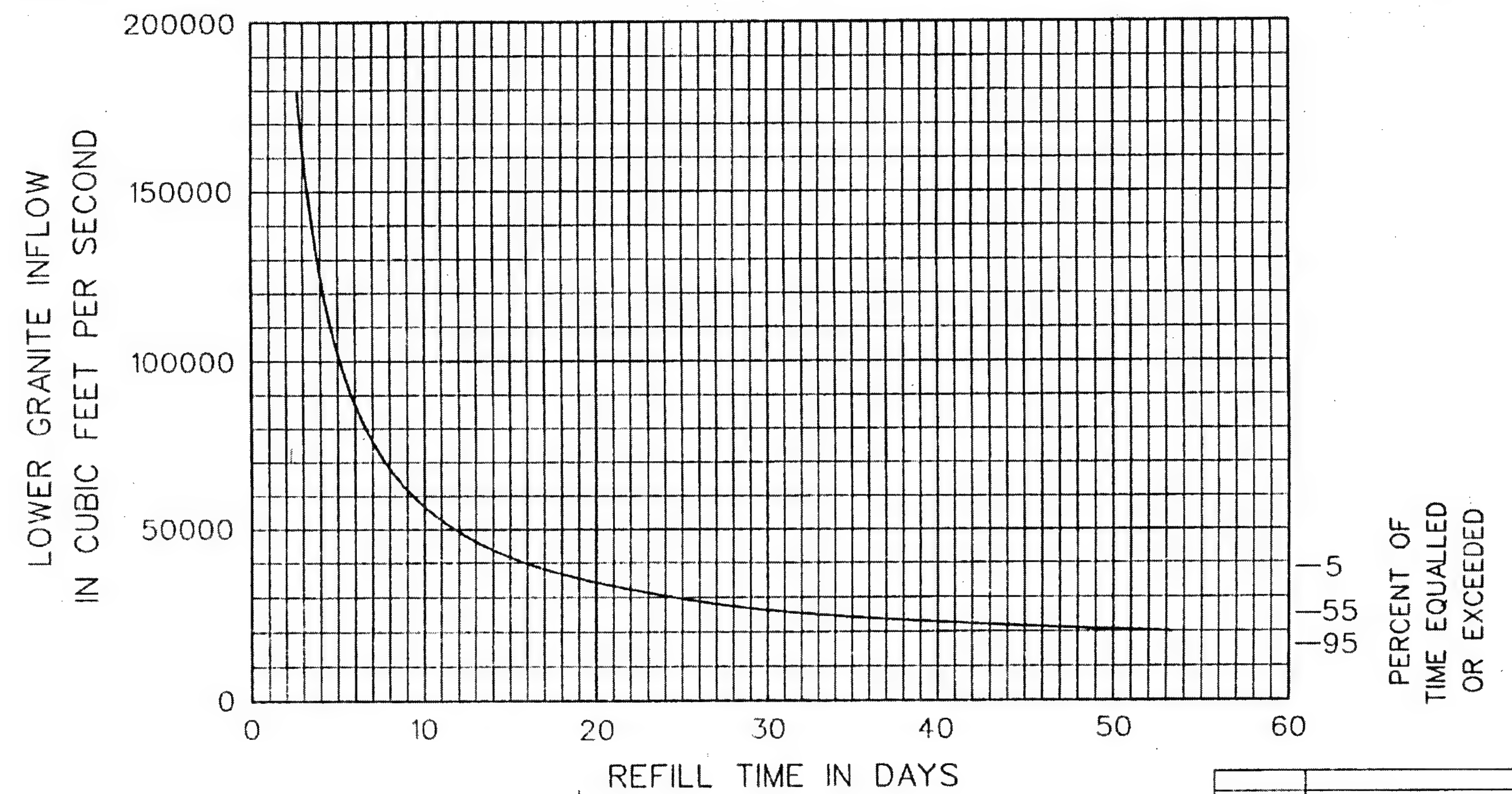
REFILL TIME FROM SPILLWAY CREST TO NORMAL FULL POOL ELEVATION

U. S. ARMY ENGINEER DISTRICT
WALLA WALLA - HYDROLOGY BRANCH

DESIGNED	DRAWN	DATE
MAXSON	SCHUSTER	9 OCT 1992

A00192

Chart 30-2.



NOTES:

1. THIS CURVE DEPICTS THE TIME TO REFILL THE FOUR LOWER SNAKE RIVER PROJECTS FROM EXISTING SPILLWAY CRESTS OF 391, 438, 581, AND 681 FEET MSL FOR ICE HARBOR, LOWER MONUMENTAL, LITTLE GOOSE, AND LOWER GRANITE, RESPECTIVELY TO NORMAL FULL POOL. THE ORDER OF REFILL IS NOT CONSIDERED.
2. A MINIMUM PROJECT RELEASE OF 11,000 CUBIC FEET PER SECOND IS CONSIDERED IN THE REFILL TIMES.
3. DURATION PERCENTAGES WERE COMPUTED FOR LOWER GRANITE INFLOWS FOR 1 SEPTEMBER THROUGH 31 OCTOBER FOR THE PERIOD 1976 THROUGH 1992.

DATE	REVISION	BY

SNAKE RIVER BASIN
SYSTEM CONFIGURATION STUDY
ICE HARBOR, LOWER MONUMENTAL, LITTLE GOOSE, & LOWER GRANITE RESERVOIRS

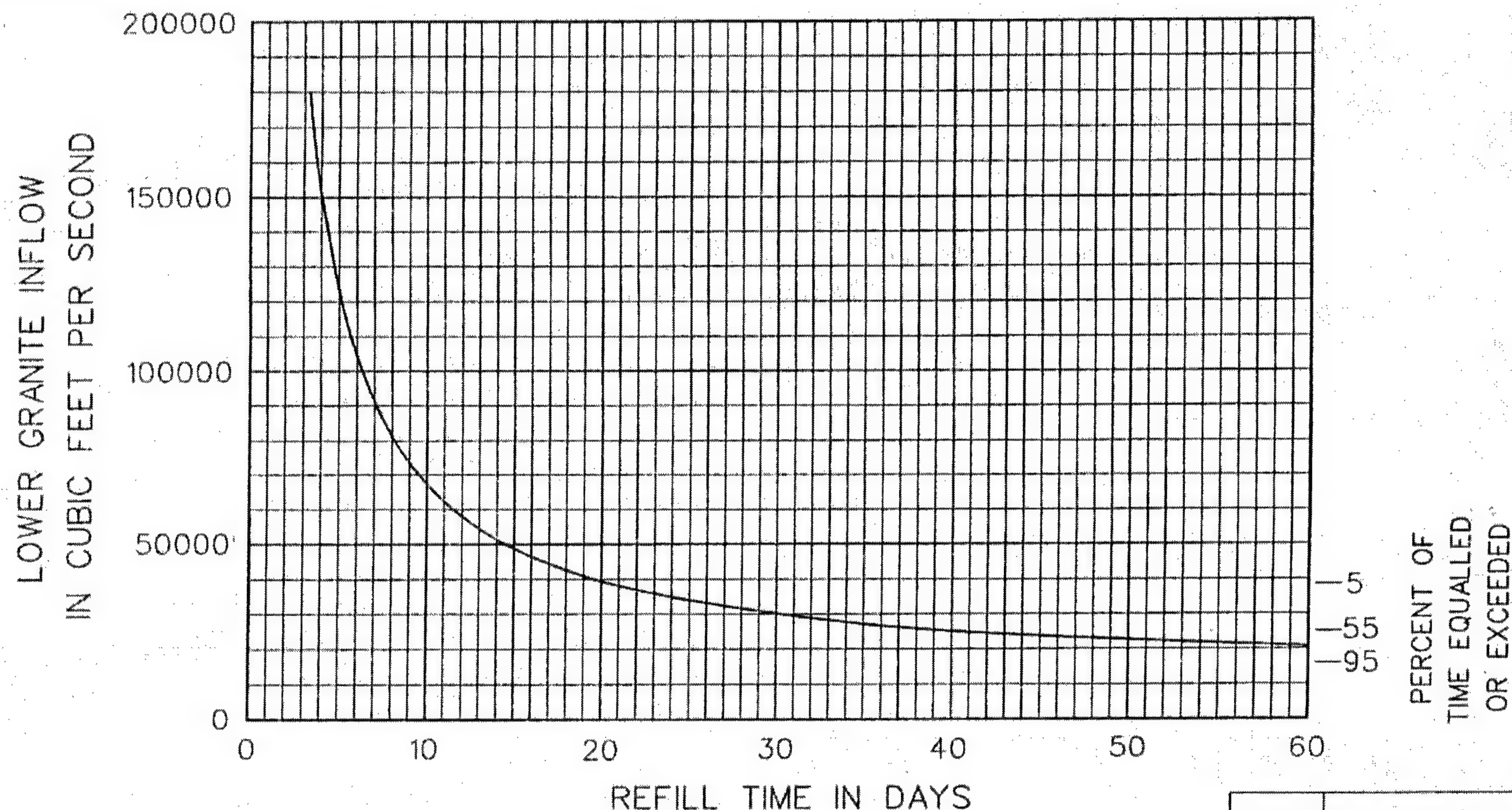
REFILL TIME FROM 33 FEET BELOW TO NORMAL FULL POOL ELEVATION

U. S. ARMY ENGINEER DISTRICT
WALLA WALLA - HYDROLOGY BRANCH

DESIGNED	DRAWN	DATE
MAXSON	SCHUSTER	9 OCT 1992

A00189

Chart 30-3.



NOTES:

1. THIS CURVE DEPICTS THE TIME TO REFILL THE FOUR LOWER SNAKE RIVER PROJECTS FROM EXISTING SPILLWAY CRESTS OF 391, 438, 581, AND 681 FEET MSL FOR ICE HARBOR, LOWER MONUMENTAL, LITTLE GOOSE, AND LOWER GRANITE, RESPECTIVELY TO NORMAL FULL POOL. THE ORDER OF REFILL IS NOT CONSIDERED.
2. A MINIMUM PROJECT RELEASE OF 11,000 CUBIC FEET PER SECOND IS CONSIDERED IN THE REFILL TIMES.
3. DURATION PERCENTAGES WERE COMPUTED FOR LOWER GRANITE INFLOWS FOR 1 SEPTEMBER THROUGH 31 OCTOBER FOR THE PERIOD 1976 THROUGH 1992.

DATE	REVISION	BY

SNAKE RIVER BASIN
SYSTEM CONFIGURATION STUDY
ICE HARBOR, LOWER MONUMENTAL, LITTLE GOOSE, AND LOWER GRANITE RESERVOIRS

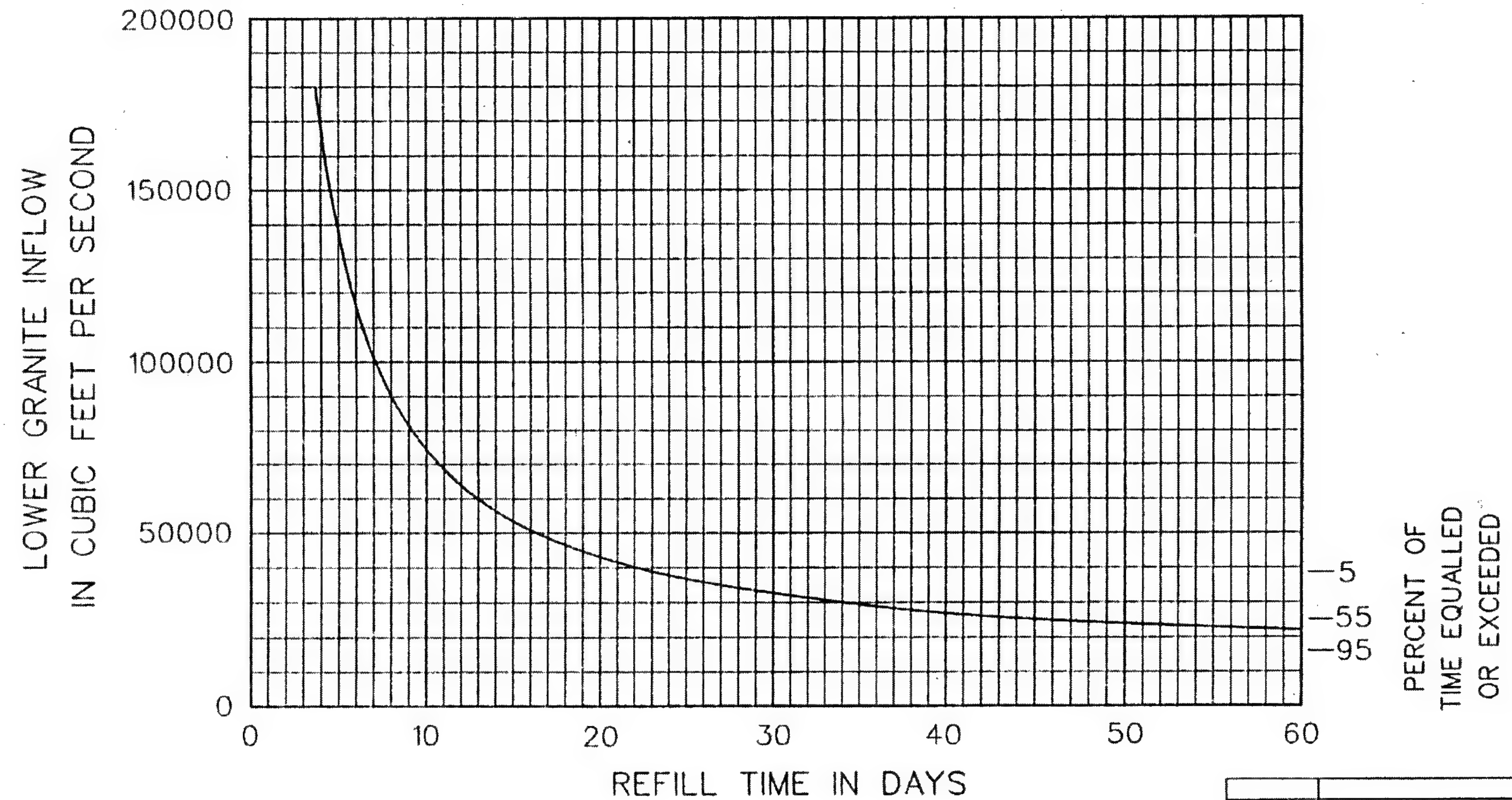
REFILL TIME FROM 43 FEET BELOW TO NORMAL FULL POOL ELEVATION

U. S. ARMY ENGINEER DISTRICT
WALLA WALLA – HYDROLOGY BRANCH

DESIGNED	DRAWN	DATE
MAXSON	SCHUSTER	9 OCT 1992

A00190

Chart 30-4.



NOTES:

1. THIS CURVE DEPICTS THE TIME TO REFILL THE FOUR LOWER SNAKE RIVER PROJECTS FROM EXISTING SPILLWAY CRESTS OF 391, 438, 581, AND 681 FEET MSL FOR ICE HARBOR, LOWER MONUMENTAL, LITTLE GOOSE, AND LOWER GRANITE, RESPECTIVELY TO NORMAL FULL POOL. THE ORDER OF REFILL IS NOT CONSIDERED.
2. A MINIMUM PROJECT RELEASE OF 11,000 CUBIC FEET PER SECOND IS CONSIDERED IN THE REFILL TIMES.
3. DURATION PERCENTAGES WERE COMPUTED FOR LOWER GRANITE INFLOWS FOR 1 SEPTEMBER THROUGH 31 OCTOBER FOR THE PERIOD 1976 THROUGH 1992.

DATE	REVISION	BY

SNAKE RIVER BASIN
SYSTEM CONFIGURATION STUDY
ICE HARBOR, LOWER MONUMENTAL, LITTLE GOOSE, AND LOWER GRANITE RESERVOIRS

REFILL TIME FROM 52 FEET BELOW TO NORMAL FULL POOL ELEVATION

U. S. ARMY ENGINEER DISTRICT
WALLA WALLA - HYDROLOGY BRANCH

DESIGNED	DRAWN	DATE
MAXSON	SCHUSTER	9 OCT 1992

A00191

Chart 30-5.

31. Literature Cited

Bariss, Nicholas. 1971. Gully Formation in the Loesses of Central Nebraska, University of Nebraska, Omaha, Nebraska, *Rocky Mountain Social Science Journal*, Volume 8, Number 2, October 1971.

Bariss, Nicholas. Gullying in a Semi-Arid Loess Region of North America, University of Nebraska, Omaha, Nebraska.

Beer, Craig Eugene and H.P. Johnson. 1963. Factors in Gully Growth in the Deep Loess Area of Western Iowa, Transactions of the American Society of Agricultural Engineers, p 237-240.

Beer, Craig Eugene. 1962. Relationship of Factors Contributing to Gully Development in Loess Soils of Western Iowa, a Doctor of Philosophy Dissertation, Iowa State University, Ames, Iowa.

Bryan, Kirk. 1926. The Palouse Soil Problem, in *Contributions to Geography of the United States*, Bulletin 790, p 21-46.

Chorley, Richard J., Stanley A. Schumm, and David E. Sugden. 1985. Geomorphology.

Fenneman, Nevin M. 1931. Physiography of the Western United States, McGraw-Hill Book Company, New York.

Kaiser, Verle G. 1975. Soil Erosion and Wheat Yields in Whitman County, Washington, *Northwest Science*, v.41, no. 2, p 86-91, 1967.

McCool, D.K. and R.I. Papendick. 1975. Variation of Suspended Sediment Load in the Palouse Region of the Pacific Northwest, Paper No. 75-2510, American Society of Agricultural Engineers, 1975.

Packer, Paul E. 1951. "Status of Research on Watershed Protection Requirements for Granitic Mountain Soils in Southwestern Idaho," Intermountain Forest and Range Experiment, U.S. Department of Agriculture, Forest Service, Ogden, Utah, October 1951.

Renard, K.G., G.R. Foster, G.A. Weesies, D.K. McCool, and D.C. Yoder. 1997. Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE), U.S. Government Printing Office, Washington D.C., 1997.

Renner, F.G. 1936. Conditions Influencing Erosion on the Boise Watershed, U.S. Department of Agriculture Technical Bulletin 528, 1936.

Symons, Lieutenant Thomas W. 1882. Report of an Examination of the Upper Columbia River and the Territory in its Vicinity, Forty-seventh Congress, 1st session, Document Number 186, U.S. Government Printing Office, Washington D.C., 1882.

U.S. Army Corps of Engineers (Corps). 1964. Walla Walla District. Water Control Manual for Ice Harbor Lock and Dam Snake River, Washington; Walla Walla, Washington; March 1964 w/ revisions.

Corps. 1970. Walla Walla District. Water Control Manual for Lower Monumental Lock and Dam Snake River, Washington; Walla Walla, Washington; May 1970 w/ revisions.

Corps. 1984. Walla Walla District. Sedimentation Study - Interim Report, Lower Granite Project, Snake River, Washington and Idaho, Walla Walla, Washington; February 1984.

Corps. 1986. Walla Walla District. Water Control Manual for Dworshak Dam and Reservoir North Fork Clearwater River, Idaho; Walla Walla, Washington; November 1986 w/ revisions.

Corps. 1987. Walla Walla District. Water Control Manual for Lower Granite Lock and Dam Snake River, Washington; Walla Walla, Washington; May 1987 w/ revisions.

Corps. 1988. Walla Walla District. Water Control Manual for Little Goose Lock and Dam Snake River, Washington; Walla Walla, Washington; February 1988 w/ revisions.

Corps. 1989. Office of the Chief of Engineers. Sedimentation Investigations of Rivers and Reservoirs (EM 1110-2-4000), Washington D.C.; 15 December 1989.

Corps. 1992a. Walla Walla District. Tri-Cities Levees, Washington, Reconnaissance Report, Walla Walla, Washington. May 1992.

Corps. 1992b. Walla Walla District. Lower Granite Sedimentation Study, Preliminary Evaluation and Progress Report, Walla Walla, Washington. December 1992.

Corps. 1993. Hydrologic Engineering Center. HEC-6 User's Manual, Scour and Deposition in Rivers and Reservoirs, Davis, California; August 1993.

U.S. Department of Agriculture (USDA). 1978. Economics, Statistics, and Cooperatives Service, Forest Service, and Soil Conservation Service, Palouse Co-operative River Basin Study, 1978.

USDA. 1982. Soil Conservation Service, Sediment Transport, Water Quality, and Changing Bed Conditions, Tucannon River, Southeastern Washington, Spokane, Washington; April 1982.

U.S. Department of the Interior, Geological Survey (USGS). 1893. A Geological Reconnaissance in Central Washington, by Israel Cook Russell, Geological Survey Bulletin 108, U.S. Government Printing Office, Washington D.C.; 1893.

USGS. 1897. A Reconnaissance in Southeastern Washington, by Israel Cook Russell, Geological Survey Water Supply and Irrigation Paper 4, U.S. Government Printing Office, Washington D.C.; 1897.

USGS. 1901a. Geology and Water Resources of Nez Perce County, Idaho, Part I, by Israel Cook Russell, Geological Survey Water Supply and Irrigation Paper 53, U.S. Government Printing Office, Washington D.C.; 1901.

USGS. 1901b. Geology and Water Resources of Nez Perce County, Idaho, Part II, by Israel Cook Russell, Geological Survey Water Supply and Irrigation Paper 54, U.S. Government Printing Office, Washington D.C.; 1901.

USGS. 1904. A Geological Reconnaissance Across the Bitterroot Range and Clearwater Mountains in Montana and Idaho, by Waldemar Lindgren, Geological Survey Professional Paper 27, U.S. Government Printing Office, Washington D.C.; 1904.

USGS. 1905. Geology and Water Resources of a Portion of East-Central Washington, by Frank C. Calkins, Geological Survey Water Supply and Irrigation Paper No. 118, U.S. Government Printing Office, Washington D.C.; 1905.

USGS. 1914. Quality of the Surface Waters of Washington, by Walton Van Vinkle, Geological Survey Water Supply Paper 339, U.S. Government Printing Office, Washington D.C.; 1914.

USGS. 1957. Quality of the Surface Waters of the United States,1952, by S.K. Love, Geological Survey Water Supply Paper 1253, U.S. Government Printing Office, Washington D.C.; 1957.

USGS. 1958. Quality of the Surface Waters of the United States,1953, by S.K. Love, Geological Survey Water Supply Paper 1293, U.S. Government Printing Office, Washington D.C.; 1958.

USGS. 1959a. Quality of the Surface Waters of the United States,1954, by S.K. Love, Geological Survey Water Supply Paper 1353, U.S. Government Printing Office, Washington D.C.; 1959.

USGS. 1959b. Quality of the Surface Waters of the United States,1955, by S.K. Love, Geological Survey Water Supply Paper 1403, U.S. Government Printing Office, Washington D.C.; 1959.

USGS. 1960. Quality of the Surface Waters of the United States,1956, by S.K. Love, Geological Survey Water Supply Paper 1453, U.S. Government Printing Office, Washington D.C.; 1960.

USGS. 1963. Effects of Hydraulic and Geologic Factors on Streamflow of the Yakima River Basin, Washington, by Hallard B. Kennison and Jack E. Sceva, Geological Survey Water Supply Paper 1595, U.S. Government Printing Office, Washington D.C.; 1963.

USGS. 1964a. Compilation of Water-Temperature Data for Oregon Streams, Open File Report, U.S. Geological Survey, Portland, Oregon, 1964.

USGS. 1964b. Geology and Groundwater Resources of the Upper Grande Ronde River Basin, Union County, Oregon, by E.R. Hampton and S.G. Brown, Geological Survey Water Supply Paper 1597, U.S. Government Printing Office, Washington D.C.; 1964.

USGS. 1968. Water Temperatures in the Lower Columbia River, by A. M. Moore, Geological Survey Circular 551, U.S. Government Printing Office, Washington D.C., 1968.

USGS. 1969a. Water Resources Data for Idaho, 1969, Part 2, Water Quality Records,1969.

USGS. 1969b. Sediment Transport by Streams in the Walla Walla River Basin, Washington and Oregon, July 1962-June 1965, by B.E. Mapes, Geological Survey Water Supply Paper 1868, U.S. Government Printing Office, Washington D.C.; 1969.

USGS. 1970. Sediment Transport by Streams in the Palouse River Basin, Washington and Idaho, July 1961-June 1965, by P.R. Boucher, Geological Survey Water Supply Paper 1899-C, U.S. Government Printing Office, Washington D.C.; 1970.

USGS. 1972. Water Resources Data for Idaho, 1972, Part 2, Water Quality Records, 1972.

USGS. 1975. The Channels and Waters of the Upper Salmon River Area, Idaho, by William W. Emmett, Geological Survey Professional Paper 870-A, U.S. Government Printing Office, Washington D.C.; 1975.

USGS. 1980. Sediment Transport in the Snake and Clearwater Rivers in the Vicinity of Lewiston, Idaho, by Michael L. Jones and Harold R. Seitz, Geological Survey Water-Resources Investigations Open File Report 80-690, U.S. Geological Branch of Distribution, Lakewood, CO., August 1980.

USGS. 1996. Total Dissolved Gas, Barometric Pressure, and Water Temperature Data, Oregon and Washington, 1996, by Dwight Q. Tanner, Howard E. Harrison, and Stuart W. McKenzie, Geological Survey Open File Report 96-662A, Portland, Oregon, 1996.

USGS. 1998. Soil Erosion in the Palouse River Basin: Indications of Improvement, by James C. Ebbert and R. Dennis Roe, Geological Survey Fact Sheet 069-98, U.S. Government Printing Office, Washington D.C., July 1998.

Vanoni, Vito. 1975. Sedimentation Engineering (ASCE Manual 54), American Society of Civil Engineers, New York, 1975.

32. Glossary

__Note__: Unless otherwise noted, the sources of information utilized in this glossary are the glossaries contained in either the U.S. Army Corps of Engineers Engineer Manual entitled River Hydraulics, EM-1110-2-1416 (Headquarters, 15 October 1993) or the U.S. Army Corps of Engineers Scour and Deposition in Rivers and Reservoirs (HEC-6) User's Manual (Hydrologic Engineering Center, August 1993).

Aggradation: The geologic process by which stream beds, floodplains, and the bottoms of other water bodies are raised in elevation by the deposition of material eroded and transported from other areas. It is the opposite of degradation.

Alluvial: Pertains to alluvium deposited by a stream or flowing water.

Alluvial Deposit: Clay, silt, sand, gravel, or other sediment deposited by the action of running or receding water.

Alluvial Stream: A stream whose channel boundary is composed of appreciable quantities of the sediments transported by the flow, and which generally changes

Alluvium: A general term for all detrital deposits resulting directly or indirectly from the sediment transported by (modern) streams; thus including the sediments laid down in river beds, floodplains, lakes, fans, and estuaries.

Armoring: The process of progressive coarsening of the bed layer by removal of fine particles until it becomes resistant to scour. The coarse layer that remains on the surface is termed the "armor layer." Armoring is a temporary condition; higher flows may destroy an armor layer and it may reform as flows decrease. Or, simply, the formation of a resistant layer of relatively large particles resulting from removal of finer particles by erosion.

Backwater Curve: Longitudinal profile of the water surface in a stream where the water surface is raised above its normal level by a natural or artificial obstruction.

Bank Migration: Lateral or horizontal movement of the banks of a streamcourse.

Bed Forms: Irregularities found on the bottom (bed) of a stream that are related to flow characteristics. They are given names such as "dunes," "ripples," and "antidunes." They are related to the transport of sediment and interact with the flow because they change the roughness of the stream bed. An analog to stream bed forms are desert sand dunes (although the physical mechanisms for their creation and movement may be different.)

Bed Load: Material moving on or near the stream bed by rolling, sliding, and sometimes making brief excursions into the flow a few diameters above the bed, i.e., "jumping." The term "saltation" is sometimes used in the place of "jumping." Bed load is bed material that moves in continuous contact with the bed; contrast with "suspended load."

Bed Material: The sediment mixture of which the moving bed is composed. In alluvial streams, bed material particles are likely to be moved at any moment or during some future flow condition.

Bed Rock: A general term for the rock, usually solid, that underlies soil or other unconsolidated, superficial material.

Boulder: A sediment particle having a diameter greater than 256 millimeters.

Boundary Roughness: The roughness of the bed and banks of a stream or river. The greater the roughness, the greater the frictional resistance to flows; and, hence, the greater the water surface elevation for any given discharge.

Calibration: Adjustment of a model's parameters such as roughness or dispersion coefficients so that it reproduces observed prototype data to acceptable accuracy.

Channel: A natural or artificial waterway which periodically or continuously contains moving water.

Clay: A sediment particle having a diameter between 0.00024 and 0.004 millimeters.

Cobble: A sediment particle having a diameter between 64 and 256 millimeters.

Cohesive Sediments: Sediments whose resistance to initial movement or erosion is affected mostly by cohesive bonds between particles.

Colloid: A sediment particle having a diameter less than 0.00024 millimeters.

Concentration of Sediment: The dry weight of sediment per unit volume of water-sediment mixture, i.e. milligrams per liter (mg/l) or parts per million (ppm).

Cross Section: Depicts the shape of the channel in which a stream flows. Measured by surveying the stream bed elevation across the stream on a line perpendicular to the flow. Necessary data for the computation of hydraulic and sediment transport information.

Cross-sectional Area: The cross-sectional area is the area of a cross section perpendicular to the direction of flow beneath the water surface.

Degradation: The geologic process by which stream beds, floodplains, and the bottoms of other water bodies are lowered in elevation by the removal of material from the boundary. It is the opposite of aggradation.

Deposition: The mechanical or chemical processes through which sediments accumulate in a (temporary) resting place. The raising of the stream bed by settlement of moving sediment that may be due to local changes in the flow, or during a single flood event.

Depth of Flow: The depth of flow is the vertical distance from the bed of a stream to the water surface.

Discharge: The discharge, usually abbreviated as "Q," is the volume of a fluid or solid passing a cross section of a stream per unit of time.

Drainage Basin: The area tributary to or draining into a lake, stream, or measuring site. See also Watershed.

Dunes: Bed forms with triangular profile that advance downstream due to net deposition of particles on the steep downstream slope. Dunes move downstream at velocities that are small relative to the streamflow velocity.

Erosion: The wearing away of the land surface by detachment and movement of soil and rock fragments through the action of moving water and other geological agents.

Floodplain: Normally dry land adjacent to a body of water such as a river, stream, lake, or ocean, which is susceptible to inundation by floodwaters.

Flow Duration Curve: A measure of the range and variability of a stream's flow. The flow duration curve represents the percent of time during which specified flow rates are exceeded at a given location. This is usually presented as a graph of flow rate (discharge) versus percent of time that flows are greater than, or equal to, that flow.

Fluvial: (1) pertaining to streams. (2) growing or living in streams or ponds. (3) produced by river action, as a fluvial plain.

Fluvial Sediment: Particles derived from rocks or biological materials which are transported by, suspended in, or deposited by streams.

Gaging Station: A selected cross section of a stream channel where one or more variables are measured continuously or periodically to record discharge or other parameters.

Geology: A science that deals with the physical history of the earth, especially as recorded in rocks and landforms.

Geomorphology: The study of landform development under processes associated with running water.

Gravel: A sediment particle having a diameter between 2 and 64 millimeters.

Hydraulic Depth: The hydraulic depth is the ratio of cross-sectional area to top width at any given elevation.

Hydraulic Radius: The hydraulic radius is the ratio of cross-sectional area to wetted perimeter at any given elevation.

Hydraulics: The study and computation of the characteristics, e.g. depth (water surface elevation), velocity, and slope of water flowing in a stream or river.

Hydrograph: A graph showing, for a given point on a stream or channel, the discharge, water surface elevation, stage, velocity, available power, or other property of water with respect to time.

Hydrology: The study of the properties, distribution, and circulation of water on the surface of the land, in the soil, and in the atmosphere.

Manning's *n* value: *n* is a coefficient of boundary roughness, *n* accounts for energy loss due to the friction between the bed and the water. In fluvial hydraulics (moveable boundary hydraulics), the Manning's *n* value usually includes the effects of other losses, such as grain roughness of the moveable bed, form roughness of the moveable bed, bank irregularities, vegetation, bend losses, and junction losses. Contraction and expansion losses are not included in Manning's *n*, and are typically accounted for separately.

Mathematical Model: A model that uses mathematical expressions (i.e., a set of equations, usually based upon fundamental physical principles) to represent a physical process.

Mean Velocity: The mean velocity is the discharge divided by the area of water at a cross section.

Model: A representation of a physical process or thing that can be used to predict the process's or thing's behavior or state.

Particle Size: A linear dimension, usually designated as "diameter," used to characterize the size of a particle. The dimension may be determined by any of several different techniques, including sedimentation sieving, micrometric measurement, or direct measurement.

Prototype: The full-sized structure, system, process, or phenomenon being modeled.

Qualitative: A relative assessment of a quantity or amount.

Quantitative: An absolute measurement of a quantity or amount.

Reach: (1) the length of a channel uniform with respect to discharge, depth, area, and slope; e.g., "typical channel reach" or "degrading reach," etc., (2) the length of a stream between two specified gaging stations, control points, or computational points.

Reservoir: An impounded body of water or controlled lake where water is collected and stored.

Ripple: Small triangular-shaped bed forms that are similar to dunes, but have much smaller heights and lengths.

Runoff: Flow that is discharged from an area by stream channels; sometimes subdivided into surface runoff, groundwater runoff, and seepage.

Sand: A sediment particle having a diameter between 0.0625 and 2 millimeters.

Scour: The enlargement of a cross section by the removal of boundary material through the action of the fluid in motion.

Sediment: (1) particles derived from rocks or biological materials that have been transported by a fluid. (2) solid material suspended in or settled from water. A collective term meaning an accumulation of soil, rock, and mineral particles transported or deposited by flowing water.

Sedimentation: Consists of five (5) fundamental processes: (1) weathering, (2) erosion, (3) transportation, (4) deposition, and (5) diagenesis, or consolidation into rock. Also refers to the gravitational settling of suspended particles that are heavier than water.

Sediment Yield: The total sediment outflow from a drainage basin in a specific period of time. It includes bed load as well as suspended load, and is usually expressed in terms of mass or volume per unit of time.

Shear Force: The shear force is the shear developed on the wetted area of the channel and it acts in the direction of flow. This force per unit wetted area is called the shear stress.

Shear Stress: Frictional force per unit of stream bed area exerted on the stream bed by the flowing water. An important factor in the movement of bed material.

Silt: A sediment particle having a diameter between 0.004 and 0.0.0625 millimeters.

Sorting: The dynamic process by which sediment particles having some particular characteristic (such as similarity of size, shape, or specific gravity) are naturally selected and separated from associated but dissimilar particles by the agents of transportation.

Stage: The stage is the vertical distance from any selected and defined datum to the water surface.

Stage-Discharge (Rating) Curve: Defines a relationship between discharge and water surface elevation at a given location.

Stream Discharge: The volume of flow passing a stream cross section in a unit of time.

Stream Gage: A device that measures and records flow characteristics such as water discharge and water surface elevation at a specific location on a stream. Sediment transport measurements are usually made at stream gate sites.

Suspended Bed Material Load: That portion of the suspended load that is composed of particle sizes found in the bed material.

Suspended Load: Includes both suspended bed material load and wash load. Sediment that moves in suspension is continuously supported in the water column by fluid turbulence.

Tail Water: The water surface elevation downstream from a structure, such as below a dam, weir, or drop structure.

Thalweg: The line following the lowest part of a valley, whether under water or not. Usually is the line following the deepest part, or middle, of the bed or channel of a river.

Top Width: The width of a stream section at the water surface, it varies with stage in most natural channels.

Total Sediment Load (Total Load): Includes bed load, suspended bed material load, and wash load. In general, total sediment load cannot be calculated or directly measured.

Transportation (Sediment): The complex processes of moving sediment particles from place to place. The principal transporting agents are flowing water and wind.

Turbidity: Turbidity is an expression of the optical property that causes light to be scattered and absorbed rather than transmitted with no change in direction or flux level through the sample. Turbidity in water is caused by suspended and colloidal matter such as clay, silt, finely divided organic and inorganic matter, and plankton and other microscopic organisms. (this description approved by Standards Methods Committee, American Public Health Association, 1994)

Wash Load: That part of the suspended load that is finer than the bed material. Wash load is limited by supply rather than hydraulics. What grain sizes constitute wash load varies with flow and location in the stream. Sampling procedures that measure suspended load will include both wash load and suspended bed material load. Normally, that is of sediment particles smaller than 0.062 millimeters.

Water Column: An imaginary vertical column of water used as a control volume for computational purposes. Usually the size of a unit area and as deep as the depth of water at that location in the river.

Watershed: A topographically defined area drained by a river/stream or system of connecting rivers/streams such that all outflow is discharged through a single outlet. Also called a drainage area.

Wetted Perimeter: The length of wetted contact between a stream of flowing water and its containing channel, measured in a direction normal (perpendicular) to the flow.

US Army Corps of Engineers®
Walla Walla District

Final

Lower Snake River Juvenile Salmon Migration Feasibility Report/ Environmental Impact Statement

Appendix G

Hydroregulations

February 2002

US Army Corps of Engineers®
Walla Walla District

Final

Lower Snake River Juvenile Salmon Migration Feasibility Report/ Environmental Impact Statement

Appendix G
Hydroregulations

Produced by

U.S. Army Corps of Engineers
Walla Walla District

February 2002

H:\WP\1346\Appendices\FEIS\G - Hydroregulations\CamRdy\App_G.doc

FOREWORD

Appendix G was prepared by the U.S. Army Corps of Engineers (Corps) along with a hydroregulation work group comprised of the Corps, the Bonneville Power Administration, the Bureau of Reclamation, the National Marine Fisheries Service, the U.S. Fish and Wildlife Service, the Northwest Power Planning Council, the Columbia River Inter Tribal Fish Commission, and Washington, Oregon, and Idaho. This appendix is one part of the overall effort of the Corps to prepare the Lower Snake River Juvenile Salmon Migration Feasibility Report/Environmental Impact Statement (FR/EIS).

The Corps has reached out to regional stakeholders (Federal agencies, tribes, states, local governmental entities, organizations, and individuals) during the development of the FR/EIS and appendices. This effort resulted in many of these regional stakeholders providing input and comments, and even drafting work products or portions of these documents. This regional input provided the Corps with an insight and perspective not found in previous processes. A great deal of this information was subsequently included in the FR/EIS and appendices; therefore, not all of the opinions and/or findings herein may reflect the official policy or position of the Corps.

This page is intentionally left blank.

CONTENTS

CONTENTS

FIGURES

TABLES

ACRONYMS AND ABBREVIATIONS

ΔS	change in reservoir storage
AEC	actual energy capability
AER	Actual Energy Regulation
aMW	average megawatt
AOP	Assured Operating Plan
ARC	Assured Refill Curve
AVE	Average
BOR	Bureau of Reclamation
BPA	Bonneville Power Administration
cfs	cubic feet per second
Corps	U.S. Army Corps of Engineers
CRC	Critical Rule Curve
CSPE	Columbia Storage Power Exchange
DOP	Detailed Operating Plan
DWR	Dworshak Project
ECC	energy content curves
ESA	Endangered Species Act
Feasibility Study	Lower Snake River Juvenile Salmon Migration Feasibility Study
FELCC	Firm Energy Load Carrying Capability
fmsl	feet above mean sea level
FR/EIS	Lower Snake River Juvenile Salmon Migration Feasibility Report/ Environmental Impact Statement
ft	feet
GCL	Grand Coulee Project
H	Head
HGH	Hungry Horse Project
HYDREG	Hydro Regulator Model
HYDROSIM	Hydro Simulation Program
HYSSR	Hydro System Seasonal Regulation Program
I	reservoir inflow
IHB	Ice Harbor Project
IJC	International Joint Commission
KAF	thousand acre-feet
kcfs	thousand cubic feet per second
khm	kilo-hectare-meter
ksfd	thousand-second-feet-days
KW	kilowatt
L	losses
LGS	Little Goose Project
LIB	Libby Project
LMN	Lower Monumental Project
LWG	Lower Granite Project
m	meter

ACRONYMS AND ABBREVIATIONS

m^3/s	cubic meters per second
MAF	million acre-feet
MAX	Maximum
MED	Median
MIN	Minimum
MOP	Minimum Operating Pool
MW	megawatt
MWh	megawatt-hour
n/a	not applicable
NMFS	National Marine Fisheries Service
NPPC	Northwest Power Planning Council
NWPP	Northwest Power Pool
O	reservoir outflow
PATH	Plan for Analyzing and Testing Hypotheses
PDP	proportional draft point
PDR	Power Discharge Requirement
PNCA	Pacific Northwest Coordination Agreement
PNW	Pacific Northwest
RKM	River Kilometer
RM	River Mile
ROD	Record of Decision
SAM	System Analysis Model
SSARR	Streamflow Synthesis and Reservoir Regulation Model
URC	Upper Rule Curve
USFWS	U.S. Fish and Wildlife Service
VECC	Variable Energy Content Curve
WSCC	Western Systems Coordinating Council

ENGLISH TO METRIC CONVERSION FACTORS

To Convert From	To	Multiply By
LENGTH CONVERSIONS:		
Inches	Millimeters	25.4
Feet	Meters	0.3048
Miles	Kilometers	1.6093
AREA CONVERSIONS:		
Acres	Hectares	0.4047
Acres	Square meters	4047
Square Miles	Square kilometers	2.590
VOLUME CONVERSIONS:		
Gallons	Cubic meters	0.003785
Cubic yards	Cubic meters	0.7646
Acre-feet	Hectare-meters	0.1234
Acre-feet	Cubic meters	1234
OTHER CONVERSIONS:		
Feet/mile	Meters/kilometer	0.1894
Tons	Kilograms	907.2
Tons/square mile	Kilograms/square kilometer	350.2703
Cubic feet/second	Cubic meters/sec	0.02832
Degrees Fahrenheit	Degrees Celsius	(Deg F –32) x (5/9)

This page intentionally left blank.

Executive Summary

The hydroregulation workgroup has completed a preliminary analysis on the hydraulic response of the hydropower system for proposed alternatives for the Lower Snake River Juvenile Salmon Migration Feasibility Study. The U.S. Army Corps of Engineers (Corps) funded a 2-year study for this workgroup to develop hydroregulation specifications for each measure under consideration, to perform the modeling, and to disseminate the modeling results to other workgroups. This analysis is still subject to changes based on further review comments.

Hydroregulations are sequential stream flow models that simulate the Columbia River Basin reservoir system under different operating requirements defined by the proposed alternatives. The hydroregulations provide a realistic monthly operation of facilities for each alternative under investigation.

Representatives of PATH (the Plan for Analyzing and Testing Hypotheses group examining salmon passage survival and life-cycle models) and other interested parties conceptually identified the alternatives and measures to be investigated by the hydroregulation modelers or hydroregulators. Below is a table showing which of the most significant operational measures were included in each alternative.

Table ES-1. Alternatives and Measures

Alternative	Columbia River Flow Augmentation	Snake River Flow Augmentation	Upper Snake Flow Augmentation (KAF)	4-Lower Snake River Dams at Natural River	John Day at Natural River	John Day at Spillway
A1	Yes	Yes	427	No	No	No
A2*	Yes	Yes	427	No	No	No
A3	Yes	Yes	427	Yes	No	No
A5	Yes	No	0	Yes	No	No
A6a	Yes	Yes	1,427	No	No	No
A6b	Yes	Yes	0	No	No	No
B1	Yes	Yes	427	Yes	Yes	No
B2	No	No	0	Yes	Yes	No
C1	Yes	Yes	427	Yes	No	Yes
C2	No	No	0	Yes	No	Yes

* A2 has no spill at Lower Granite, Little Goose, Lower Monumental, and McNary.

Four alternatives were developed to assess John Day Dam operation at the natural river and spillway levels. These alternatives were used to illustrate the effect that different operating levels at John Day Dam would have on the Lower Snake River Juvenile Salmon Migration Feasibility Study. This study will not be used to make a decision regarding drawdown of the John Day Dam.

Hydroregulators representing different interests in the region met to discuss the methodology for modeling the alternatives and to develop the detailed hydroregulation specifications for each one. These specifications were reviewed by a broader agency, PATH, and an economic group before the modeling began.

Results from the hydroregulations were used by other work groups participating in the Lower Snake River Juvenile Salmon Migration Feasibility Study to determine the economic benefit of operating the system under the specified set of measures for each alternative. Outputs of the modeling include regulated steam flow, end-of-month elevations, tailwater elevations, spill, project generation, and system generation. The Hydropower Impact Team was one of the major users of the modeling results. They used the project and system generation in their production cost models to determine the costs for or impacts of meeting system load under each alternative. PATH used the regulated flow, etc., to elevate downstream survival.

A second model in the region was used to perform hydroregulation studies. The results from this modeling provided the region with another analysis tool. The two models generally matched, even though two different modeling procedures were used.

Breaching of the four lower Snake River dams, Lower Granite, Little Goose, Lower Monumental, and Ice Harbor, would eliminate 3,033 megawatts of installed nameplate capacity. Eliminating this capacity would impact the system by removing the capability to generate 1,200 average megawatts of energy a year, based on a August 1, 1928, through July 31, 1989, historical streamflow record. The hydroregulation studies showed that some of the generation that would be lost by breaching these power generation facilities would likely be replaced by other projects in the Pacific Northwest.

1. Introduction

1.1 Scope

The hydroregulation work group is composed of representatives from the U.S. Army Corps of Engineers (Corps), Bonneville Power Administration (BPA), U.S. Bureau of Reclamation (BOR), National Marine Fisheries Services (NMFS), U.S. Fish and Wildlife Service (USFWS), Northwest Power Planning Council (NPPC), Columbia River Inter-Tribal Fish Commission, and states. This group was responsible for specifying the requirements and using the computer hydroregulation models to simulate the operation of the river system for all of the alternatives evaluated in the Lower Snake River Juvenile Salmon Migration Feasibility Study (Feasibility Study). These models are complex computer programs that sequentially route streamflows through each hydropower facility in the system, calculating the regulated stream flows, reservoir elevations, spill, power generation, and other information at each facility and pertinent control points in the Columbia River Basin. Hydroregulation specifications for each alternative were developed through numerous work group meetings. Each specification was reviewed to ensure that the system operation scenario could be adequately modeled to allow evaluation of each alternative. The specifications were then reviewed by a broader group that included, i.e., the Implementation Team, Plan for Analyzing and Testing Hypotheses (PATH), etc. After this wider review was completed the hydroregulations were run and results were summarized.

1.2 Study Process

The first step was to develop a hydroregulation specification for each alternative. These specifications were coordinated with the work groups and others to ensure that alternatives were described in sufficient detail to model the reservoir system under each scenario. The computer simulation results were then provided to work groups and other interested parties. Although the Corps and BPA performed the hydroregulation studies, all members of the hydropower group actively participated in reviewing the results prior to providing them to the other work groups. The hydroregulation results provided to other work groups consisted of project data such as average monthly flow, end-of-month elevation and other similar information, as well as system-wide data such as monthly energy generation.

This page is intentionally left blank.

2. The Lower Snake River Hydropower Facilities

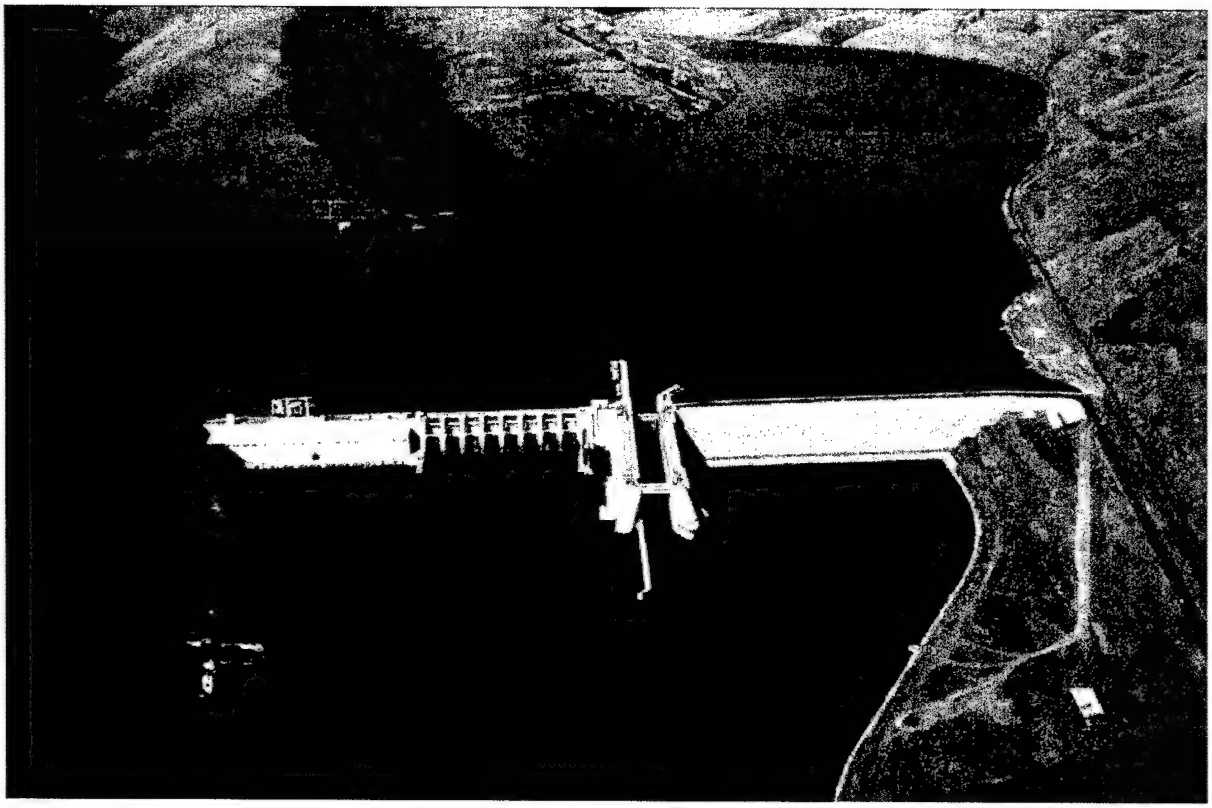


Figure 2-1. Lower Granite Dam

2.1 Lower Granite

2.1.1 Description

Stream:	Snake River (173 RKM) (RM 107.5)
Location:	Almota, Washington
Owner:	U.S. Army Corps of Engineers, Walla Walla District
Project Authorization:	PL 79-14, 1945
Project Uses:	Power, Navigation, Fish and Wildlife, Recreation, Irrigation
Type of Project:	Run-of-river
Lake:	Lower Granite Lake

2.1.2 Status and History

Lower Granite was authorized by PL 79-14 in accordance with a plan submitted in House Document 704, 75th Congress, 1945. The initial hydropower facility with units 1 through 3 was completed in 1975. The additional units, 4 through 6 were completed in 1978.

2.1.3 Lewiston Gage Elevation – m (ft)

Maximum pool 231.6 (760.0)

Normal full pool 224.9 (738.0)

Minimum pool 223.4 (733.0)

Maximum elevation for flood control

July 15 - December 14 ....224.9 (738.0)

December 15 - March 14 ....224.6 (737.0)[1/]

March 15 - July 14 ....224.9 (737.7)[1/]

2.1.4 East Lewiston Gage Elevation –m (ft)

Full pool (150,000 cubic feet per second [cfs] in Clearwater at Spalding) 226.9 (744.4)

2.1.5 Forebay Elevation – m (ft)

Maximum pool 227.5 (746.5)

Normal full pool 224.9 (738.0)

Normal minimum pool 223.4 (733.0)

For flood control

Minimum for inflows of 250,000 cfs or greater 220.7 (724.0)

Maximum for inflows of 120,000 cfs or greater 223.7 (734.0)

2.1.6 Discharge – m^3/s (cfs)

Minimum

December-February .... Zero

March-November 325.6 (11,500)

Maximum rate of change per hour 1,982.38 (70,000)

2.1.7 Powerhouse

Number of units 6

Nameplate capacity (6 @ 135 megawatts [MW]) ....810 MW

Overload capacity (6 @ 155.3 MW) ....932 MW

Hydraulic capacity ....3,681.9 m^3/s (130,000 cfs)

[1/] For inflows greater than 1,415.84 m^3/s (50,000 cfs), otherwise maximum elevation is 224.94 m (738.0 ft).

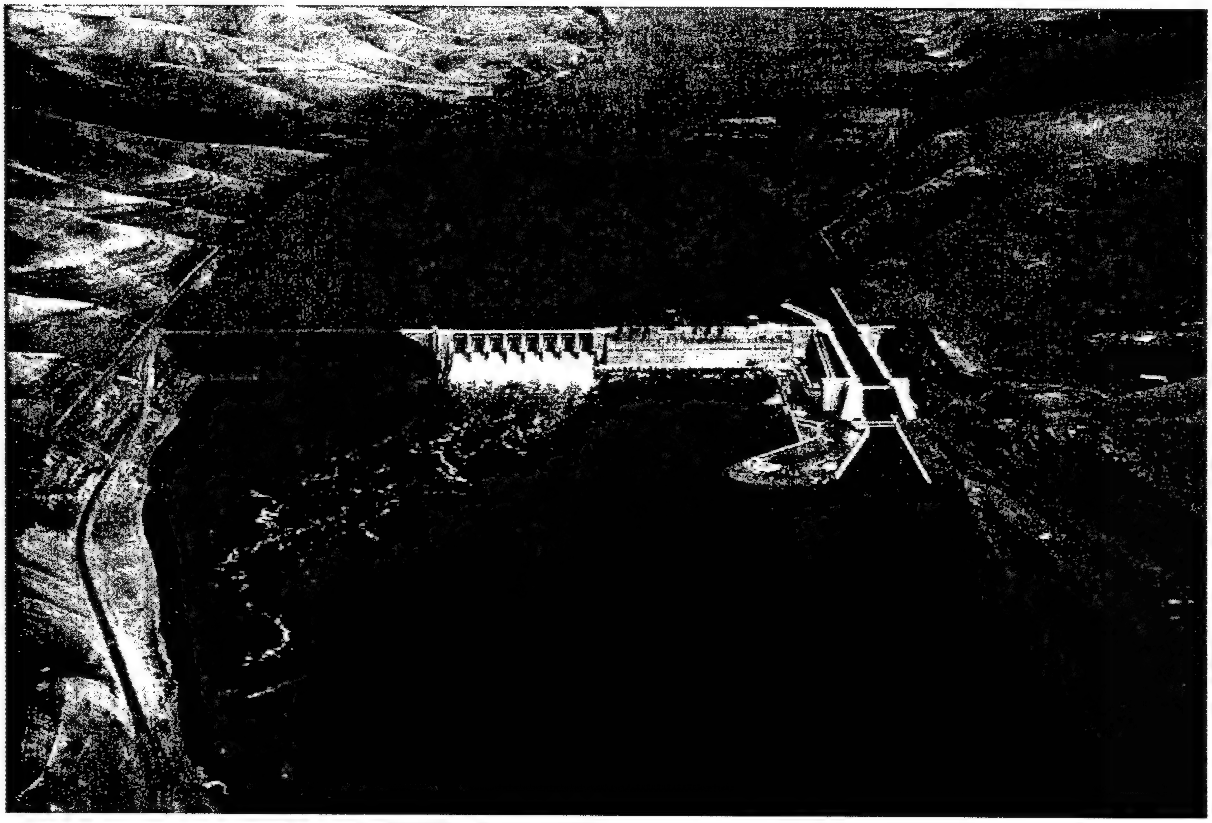


Figure 2-2. Little Goose Dam

2.2 Little Goose

2.2.1 Description

Stream:	Snake River (112.7 RKM) (RM 70.3)
Location:	Starbuck, Washington
Owner:	U.S. Army Corps of Engineers, Walla Walla District
Project Authorization:	PL 79-14, 1945
Project Uses:	Power, Navigation, Fish and Wildlife, Recreation, Irrigation
Type of Project:	Run-of-river
Lake:	Lake Bryan

2.2.2 Status and History

Little Goose was authorized by PL 79-14 in accordance with a plan submitted in House Document 704, 75th Congress, 1945. The initial hydropower facility with units 1 through 3 was completed in 1970. The additional units 4 through 6 were completed in 1978.

2.2.3 Lake Elevation – m (ft)

Maximum pool 197.1 (646.5)

Full pool .... 194.5 (638.0)[1/]

Minimum pool .... 192.9 (633.0)[1/]

2.2.4 Discharge – m^3/s (cfs)

Minimum

December-February .... Zero

March-November 325.6 (11,500)

Maximum rate of change per hour .... 1,982.2 (70,000)[2/]

2.2.5 Powerhouse

Number of units 6

Nameplate capacity (6 @ 135 MW) .... 810 MW

Overload capacity (6 @ 155.3 MW) .... 932 MW

Hydraulic capacity .... 3,681.2 m^3/s (130,000 cfs)

[1/] Project Engineer can authorize lake to fill to elevation 194.6 m (638.5 ft) or draft to elevation 192.8 m (632.5 ft) to allow for unexpected events.
[2/] Based on 0.4572 m/hour (1.5 ft/hour) change.

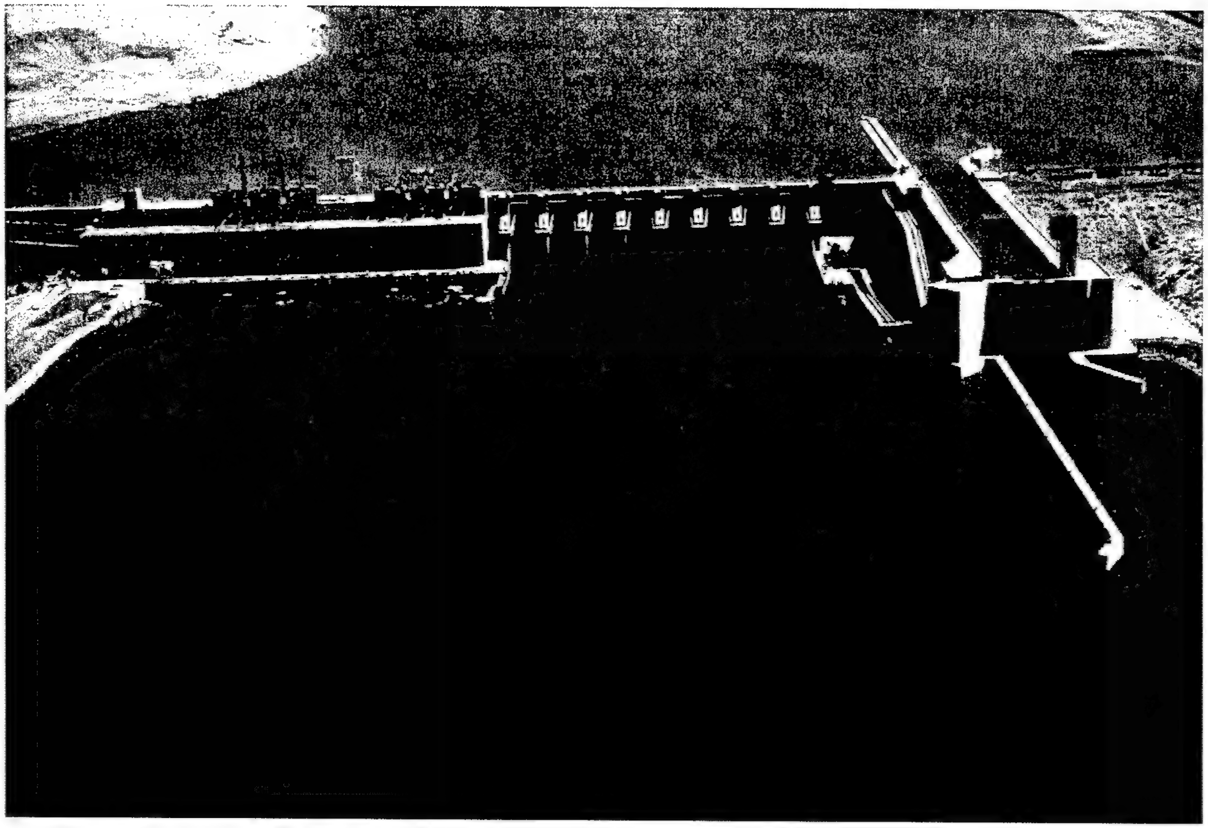


Figure 2-3. Lower Monumental Dam

2.3 Lower Monumental

2.3.1 Description

Stream:	Snake River (66.9 RKM) (RM 41.6)
Location:	Matthaw, Washington
Owner:	U.S. Army Corps of Engineers, Walla Walla District
Project Authorization:	PL 79-14, 1945
Project Uses:	Power, Navigation, Fish and Wildlife, Recreation, Irrigation
Type of Project:	Run-of-river
Lake:	Lake Herbert G. West

2.3.2 Status and History

Lower Monumental was authorized by PL 79-14 in accordance with a plan submitted in House Document 704, 75th Congress, 1945. The initial hydropower facility with units 1 through 3 was completed in 1970. The additional units, 4 through 6 were completed in 1978.

2.3.3 Lake Elevation – m (ft)

Maximum pool 167.1 (548.3)

Normal pool .... 164.6 (540.0)[1/]

Minimum pool .... 163.7 (537.0)[1/]

2.3.4 Discharge - m^3/s (cfs)

Minimum

December-February .... Zero

March-November 325.6 (11,500)

Maximum rate of change per hour .... 1,982.2 (70,000)[2/]

2/ Based on 1.5 ft/hour change.

2.3.5 Powerhouse

Number of units 6

Nameplate capacity (6 @ 135 MW) .... 810 MW

Overload capacity (6 @ 155 MW) .... 930 MW

Hydraulic capacity .... 3,681.2 m^3/s (130,000 cfs)

[1/] Project Engineer can authorize lake to fill to elevation 164.7 m (540.5 ft) or draft to elevation 163.5 m (536.5 ft) to allow for unexpected events.
[2/] Based on 0.4572 m/hour (1.5 ft/hour) change.

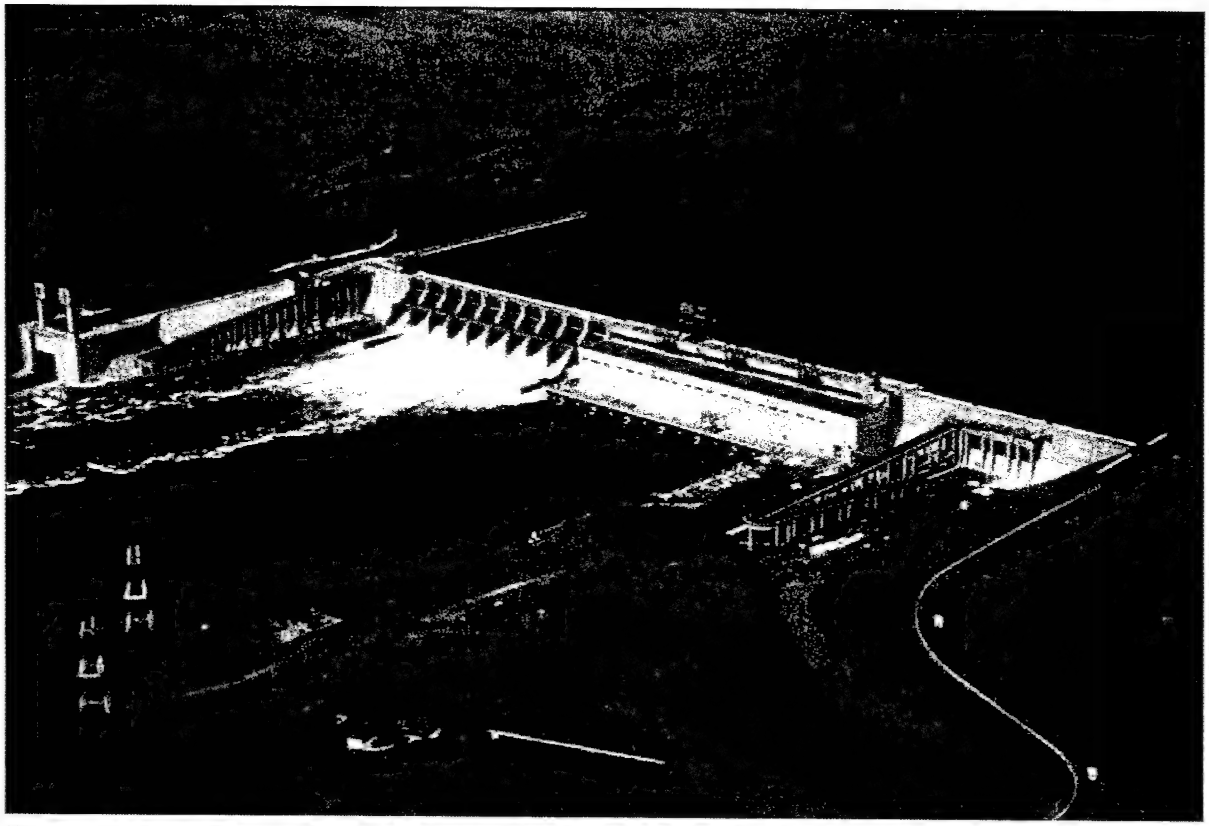


Figure 2-4. Ice Harbor Dam

2.4 Ice Harbor

2.4.1 Description

Stream:	Snake River (15.6 RKM) (RM 9.7)
Location:	Pasco, Washington
Owner:	U.S. Army Corps of Engineers, Walla Walla District
Project Authorization:	PL 79-14, 1945
Project Uses:	Power, Navigation, Fish and Wildlife, Recreation, Irrigation
Type of Project:	Run-of-river
Lake:	Lake Sacajawea

2.4.2 Status and History

Ice Harbor was authorized by PL 79-14 in accordance with a plan submitted in House Document 704, 75th Congress, 1945. The initial hydropower facility with units 1 through 3 was completed in 1962. The additional units 4 through 6 were completed in 1976.

2.4.3 Lake Elevation – m (ft)

Maximum pool 135.9 (446.0)

Full pool .... 134.1 (440.0)[1/]

Minimum pool .... 133.2 (437.0)[1/]

2.4.4 Discharge – m^3/s (cfs)

Minimum

December-February .... Zero

March-July 269.0 (9,500)

August-November 212.4 (7,500)

Maximum rate of change per hour 566.3 (20,000)

2.4.5 Powerhouse

Number of units 6

Nameplate capacity (3 @ 90 MW, 3 @ 111 MW) .... 603 MW

Overload capacity (3 @ 103.5 MW, 3 @ 127.5 MW) .... 693 MW

Hydraulic capacity .... 3,001.6 m^3/s (106,000 cfs)

[1/] Project Engineer may authorize lake level to fill 0.2 m (0.5 ft) above normal full pool or draft 0.2 m (0.5 feet) below minimum pool to allow for unexpected events.

3. Project Operating Limits

3.1 A Review of Hydroregulation Modeling

Water surges past the giant turbines and into the tailrace at Grand Coulee Dam. The tailwater below the dam rises, and the current swells as the Columbia River moves along its 1,931.2-km (1,200-mile) journey to the Pacific Ocean. Eighty km (50 miles) downstream at Chief Joseph Dam, operators will either hold back some of the flow or release it all on to Wells, Rocky Reach, Rock Island, Wanapum, and Priest Rapids dams.

From one project to the next, runoff from Canadian and Northwest snowfields makes its way down the river. Streamflows build and diminish, and reservoir elevations rise and fall as the water enters man-made lakes and is released through powerhouses and over spillways.

Hydroregulation—regulating water—is the process planners and operators use to make decisions about routing water through the series of hydropower projects in the Columbia River Basin. Those decisions are geared to make the most efficient use of the water in the river and its tributaries, and to meet multiple objectives—from controlling floods to irrigating crops to generating electricity. Regulating a system as complex as the Columbia River requires continuous planning and powerful tools.

Today, planning and regulation are processes assisted by automation. The tools of the trade are sophisticated computer programs that in a matter of minutes can calculate the river system's response to a variety of streamflow and operating conditions. The programs are also referred to as "models" because they model or simulate operations of the river system. From the data the models provide, analysts can estimate the system-wide impacts of projected operations.

This chapter describes the concept of hydroregulation modeling and how these computer models are used to determine flows, elevations, and other information for projects in the system from which environmental effects are estimated.

3.2 The Role of Models in Planning

3.2.1 Why We Need Computer Models

The Columbia River Basin covers 668,216.9 square km (258,000 square miles). The Columbia River and dozens of large tributaries drain this area, which extends from Canada to Nevada and from western Wyoming to the Pacific Ocean.

There are more than 150 dams and reservoirs on the coordinated river system—31 of them operated by Federal agencies—that work together to satisfy many needs. Hydroregulation models simulate how major projects in this system will react to changes in operations and to a wide range of runoff conditions. They also help plan how to use the water most efficiently.

Within the Columbia Basin, 10 major river uses are considered: navigation, flood control, irrigation and water supply, electric power generation, anadromous fish migration, resident fish habitat, wildlife habitat, recreation, water quality, and protection of cultural and historical sites.

What happens at each project to meet one or more of these objectives has an effect on other projects, both upstream and downstream. Hydroregulation models enlarge the planners' ability to analyze how the variables interact when there is more or less water in the system and when operating changes are considered for any or all projects.

Calculations that would take weeks and months to complete by hand take minutes with a computer. The speed with which the computer processes data makes it possible to consider far more information and to make timely and precise adjustments to operations.

3.2.2 When Were the Models Developed

Computer models have become so pervasive in the planning environment that it is hard to remember life without them. But in the 1930s, 40s, and 50s, when the hydropower system was smaller and less complex, hydroregulation was done using mechanical desk calculators and hand-drawn spreadsheets. This limited the amount of operating information that could be analyzed. Operations at each project were updated individually.

Hydroregulation models began to replace hand calculations in the late 1950s and early 1960s. The comprehensive planning models used today by the Corps and BPA have their roots in mainframe computer programs that were developed in the mid-1950s. The models continue to evolve as computer capabilities expand, precision in modeling increases, and river operations become more complicated.

3.2.3 The Columbia River Models

There are three primary hydroregulation models used today for medium- and long-term planning on the Columbia River: the Hydro System Seasonal Regulation Program (HYSSR), the Hydro Simulation Program (HYDROSIM), and the Pacific Northwest Coordination Agreement Seasonal Regulation Program (HYDREG).

On a conceptual level, the models are almost identical, except for the determination of energy and capacity. HYSSR uses characteristics of the operating unit to determine the efficiency in the hydropower equation. HYDROSIM and HYDREG use a range of head-to-kilowatt ratios to determine the energy and capacity. Since the agencies that designed and use them have distinct missions, each does have a unique point-of-view. The models were developed independently and are used to perform studies based on specific agency and constituent needs. Information and expertise is often shared among the agencies and the analysts, and in some instances, one model produces data that is used for studies run on another model.

HYSSR is the oldest of the three models. It has its genesis in a model developed by the Corps for its 1958 comprehensive system planning study. HYSSR simulates the characteristics of the Northwest hydropower system under varying electric energy requirement (load) and streamflow conditions, over an extended period of time.

HYDROSIM was developed by BPA in 1990 and 1991. It evolved from earlier programs called HYDRO2 and HYDRO6, which were written in the 1960s. Like HYSSR, HYDROSIM simulates the operating characteristics of the Northwest hydropower system under varying load and flow conditions, over an extended period of time.

HYDREG was originally developed in the 1960s at BPA, but it is now maintained and operated by the Northwest Power Pool (NWPP). HYDREG is used to establish seasonal guidelines for coordinated operation of hydro projects included in the Pacific Northwest Coordination Agreement (PNCA). The guidelines maximize power benefits while satisfying multiple non-power uses of the river system.

3.3 The Basics of Streamflow Routing

3.3.1 The Continuity Equation

Hydroregulation models are sequential streamflow routing models. At the heart of each model is the same calculation. It is called the continuity equation, and it goes like this:

The average reservoir outflow (O) in any time period is equal to the average reservoir inflow (I) during the same period minus the change in reservoir storage (ΔS) minus the losses (L).

Put another way, $O = I - \Delta S - L$.

For each dam in the system in a given time period, the program calculates what the outflow would be given:

- the inflow (from natural runoff and releases from any upstream projects),
- the change in storage at that dam (ΔS is positive if water is added to storage; ΔS is negative if water is released from storage), and
- losses (from diversions, withdrawals, or evaporation).

In many cases, the objective of system operation is to provide a particular flow on a river reach for navigation, fish passage, or power generation. The problem then is to determine how storage must change in the reservoir to ensure that this flow requirement is met. In such cases, the continuity equation would be set up and solved as follows:

$$\Delta S = I - O - L.$$

The calculation in this instance determines the change in storage given inflow, outflow, and losses. The model repeats the continuity equation for each project considered and for each time period in an analysis. The model calculates this information sequentially in time. In a full system analysis, the computation starts with the uppermost storage reservoir on the system. The outflow at the first project, plus or minus any major changes along the way, such as an irrigation diversion or the confluence with a tributary, becomes the inflow at the next project. And so the model continues, calculating the streamflows and reservoir elevations for the time period at every project on the system.

3.3.2 Using the Models to Meet Objectives

Hydroregulation models can be used to help determine how to meet a variety of operating objectives. For example, one of the objectives on the Columbia River System is power generation. The models first compute the outflow at each dam. Using another set of equations, the outflow can be converted to electrical power production in megawatts (MW).

Energy generation relies on project flows. The amount of power produced depends on three factors:

1. How much water flows through the turbines, usually measured in cubic meters per second (m^3/s) [cubic feet per second (cfs)].
2. The vertical distance the water falls, called "head." This is the difference between the height of the water behind the dam (forebay elevation) and the height of the water below the dam (tailwater elevation) measured in meters (feet).
3. The efficiency of the generating equipment. Hydropower project efficiencies generally range from 85 to 95 percent.

The equation for calculating how much power can be generated at a project is:

$$\text{Power (KW)} = \frac{\text{Flow (cfs) x Head (ft) x Efficiency (\%)}}{11.8}$$

$$P = \frac{Q \times H \times E}{11.8}$$

As an example: Power from 100,000 cfs of water flowing through Grand Coulee at full pool (El 1,290 ft) would be calculated as follows:

Tailwater = 962 ft at 100,000 cfs discharge

Head = 1290 - 962 = 328 ft

Efficiency = 88 %

$$\text{so, } P = \frac{100{,}000 \times 328 \times 0.88}{11.8} = 2{,}450{,}000 \text{ KW} = 2{,}450 \text{ MW}$$

Once the conversion to power is made, the model adds up the power generation in MWs determined for all of the projects. The result is a figure that represents the system-wide power output in MWs.

Flood control is another key objective in Columbia River operations. Maximum flows, above which flooding will occur, have been established at key points on the river. Streamflow routing models can help determine how much water must be stored in the reservoirs during flood periods so that keypoints in the rivers will be kept below flood levels.

At Vancouver, Washington, for instance, flows that exceed 16,990.1 m^3/s (600,000 cfs) will cause minor flood damages and flows that exceed 21,237.6 m^3/s (750,000 cfs) will cause major damages. A model can demonstrate whether planned operations upriver can contain the water or whether the maximum flow at Vancouver will be exceeded.

Hydroregulation models can be used to assess whether planned operations will provide flows adequate to protect fish and wildlife habitat at various places on the river and to move juvenile salmon to the ocean. For example, the 1995 Biological Opinion aims to achieve a minimum flow objective during the spring and summer at McNary Dam on the Columbia River and at Lower Granite Dam on the Snake River. This helps fish move more quickly between projects. The models

are used to determine how much water must be released from storage projects to ensure that these flow objectives are met.

On a complex river system such as the Columbia, where there are numerous competing river uses, streamflow routing models help in planning operations that attempt to satisfy a combination of objectives at the same time. The three models discussed in this chapter consider all system uses simultaneously.

3.3.3 Control Points

The previous discussion touched on an essential part of the streamflow routing models—control points. Control points are identified and characterized in the models. They are points on the river where streamflow or elevation targets or both have been established and where they are measured or gauged. In the Columbia River system models, all of the run-of-river dams and storage reservoirs are control points.

There are other control points on the system where flow or elevation targets have been established to meet a particular need. At Vernita Bar on the mid-Columbia River, for example, a seasonal flow target protects chinook salmon spawning grounds. Releases from Hells Canyon Dam are made to keep an adequate navigation depth on the Snake River downstream at Lime Point, another example of a control point. And, as noted earlier, Vancouver, Washington, is the control point used to gage flood control operations to protect the highly developed areas along the lower Columbia River.

Given an operating scenario, the models attempt to operate the reservoir system to meet the specified objectives, and they report elevations and/or streamflows at each control point. If the computer output shows that a certain operation will not meet the objectives at one or more points, adjustments to the operating criteria may be made to bring outcomes closer. For example, more water may be held upriver if the elevation at a downstream control point is too high. Additional water may be released from a reservoir if the flow at a downstream control point is too low.

It should be noted, however, that at times not all of the targets could be met simultaneously. The models have built-in priority lists (which can be changed if necessary) for which some targets take precedence over others at a given control point. For example, flood control objectives always take precedence over hydropower requirements. This topic appears again in Section 3.6 where specific types of model runs are described. Table 3-1 provides a list of projects and control points for which data are output from the hydroregulation models in a full-scale analysis.

3.4 The Model Inputs

A product is only as good as the parts that go into it. Therefore, the output of the hydroregulation models is only as up-to-date and accurate as the data that are input. The models themselves can be run in a matter of minutes. Preparing the data for a run can take weeks.

Hydroregulation models are general-purpose models, designed to be driven by the data. Each model is basically a suite of programs. The "hydroregulator" is the centerpiece of the models and consists of 20 to 30 subroutines. As many as 20 ancillary programs prepare data files that are used by the hydroregulation models. The key pieces of input data are described below. Much of the data for each model are stored as tables and graphs in master project files.

Table 3-1. Hydroregulation Output Data Locations

Name	Location
Mica	Columbia River, British Columbia, Canada
Arrow	Columbia River, Castlegar, British Columbia
Libby	Kootenai River, Libby, Montana
Bonners Ferry	Kootenai River, Bonners Ferry, Montana
Duncan	Columbia River, British Columbia, Canada
Corra Linn	Columbia River, Nelson, British Columbia
Brilliant	Columbia River, Castlegar, British Columbia
Hungry Horse	Flathead River, Hungry Horse, Montana
Columbia Falls	Flathead River, Columbia Falls, Montana
Kerr	Flathead River, Polson, Montana
Albeni Falls	Pend Oreille River, Newport, Washington
Grand Coulee	Columbia River, Grand Coulee, Washington
Chief Joseph	Columbia River, Bridgeport, Washington
Wells	Columbia River, Azwell, Washington
Rocky Reach	Columbia River, Wenatchee, Washington
Rock Island	Columbia River, Wenatchee, Washington
Wanapum	Columbia River, Ephrata, Washington
Priest Rapids	Columbia River, Ephrata, Washington
Brownlee	Snake River, Cambridge, Idaho
Dworshak	Snake River, Ahsahka, Idaho
Spalding	Snake River, Spalding, Idaho
Lower Granite	Snake River, Almota, Washington
Little Goose	Snake River, Starbuck, Washington
Lower Monumental	Snake River, Matthaw, Washington
Ice Harbor	Snake River, Pasco, Washington
McNary	Columbia River, Umatilla, Oregon
John Day	Columbia River, Rufus, Oregon
The Dalles	Columbia River, The Dalles, Oregon
Bonneville	Columbia River, Bonneville, Oregon

3.4.1 Streamflow Records

Streamflow records are the backbone of the hydroregulation studies. These records are essentially the unregulated flow of water at various points in the system. The Columbia River hydroregulation models currently have a 60-year historical streamflow record, 1928 to 1989. (The record is periodically extended, and 10 more years will soon be added.) The streamflow measurements recorded for these years are adjusted to account for storage change, evaporation, and irrigation

depletions since they were gathered. The adjustments are made to simulate natural streamflows as closely as possible and to put the entire set of streamflows on a common base.

For example, the irrigation system in the region was developed gradually. Measurements taken in 1928 at any control point on the river would not reflect the level of irrigation depletions that now take place. The records are adjusted on a 10-year cycle to recognize current conditions. They also reflect current operation of tributary reservoirs that are not modeled in the hydroregulator, such as those in the upper Snake, Yakima, and Deschutes basins. In essence, the model simulates what would happen on today's river system given the precipitation and weather conditions that actually occurred in 1928. The source for the current streamflow data is the Columbia River Water Management Group's publication, *1990 Level Modified Streamflow*, dated July 1993.

3.4.2 Project Characteristics

The models also incorporate the physical characteristics of the projects in the Columbia River System. These include minimum and maximum reservoir elevations, storage-elevation relationships, tailwater elevations, and power plant characteristics.

The number of projects for which this information is included varies among the models. Normally, it can change with the particular study or operation being simulated. HYSSR and HYDROSIM use 80, but they also performs studies that use only 36. The HYDREG, includes the largest number of projects of 150.

3.4.3 Project Operating Requirements

Operating requirements are the power production and non-power requirements that define a project's operation. These include the maximum and minimum amount of water that can be released from a project at one time (discharge), and the maximum and minimum reservoir volume content. These requirements may serve to protect areas downstream from a project. For example, a large instantaneous release could endanger fish spawning grounds below a dam. Requirements may also aim to preserve resources at a reservoir, e.g., when water is drawn down too low, resident fish and shoreline vegetation suffer.

Many operating requirements are seasonal. For example, to keep rivers from overflowing their banks during the high runoff period, reservoirs must be drawn down before the middle of April in anticipation of the spring snowmelt. Reservoir elevations are allowed to go higher in July, when the danger of flooding is gone, and vacationers want a full lake for boating. Tables in the model incorporate these seasonal variations. Normally, operating requirements are specified by the project owners and submitted to the NWPP for PNCA planning.

3.4.4 System Power Loads

Hydroregulation models are used to compute the system's ability to meet electricity loads (the amount of power that customers of the power system need at any given time) in the Northwest and to determine how much electricity to sell outside the region. Electricity loads are input to the models. Different hydroregulatory studies answer different questions: Is the system capable of meeting the projected load? How much power can be generated under a given set of operating conditions? Will thermal generation be needed in addition to hydropower generation to meet the loads? If so, how much?

3.4.5 Thermal Resources

The models may incorporate other non-hydropower, thermal power-generating resources, such as coal and nuclear (thermal) plants, as part of the computation in certain studies. The ability of these resources to contribute to the region's power supply is a consideration in determining how and whether the region's generating resources can meet current and future loads. Thermal plant operation affects the regulations for reservoirs in the coordinated system.

3.4.6 Rule Curves

Rule curves represent seasonal reservoir water level objectives and provide guidance in meeting project purposes. In some cases, the curves set elevations that must be met in each time period. At other times, they specify upper or lower elevations that are not to be violated. There are also occasions when rule curves define a range over which operations are permitted. Rule curves can be a product of the hydroregulation models, and they can be used as input data to determine reservoir operations.

The operating year on the Columbia River System is August 1 through July 31. Before each new operating year, studies are made using the hydroregulation models and historical streamflow records to derive the rule curves for multipurpose operation of the dams on the river. The models then use the rule curves to predict how much energy could be produced during the coming year under differing water conditions.

3.4.7 Ranges of Requirements

One valuable use of the hydroregulation models is to test ranges of operating requirements to evaluate their impact on project power outputs and other river uses. For example, possible operating scenarios may be established to compare current operations with a hypothetical or future situation. The models will compute and report the flows and elevations that would result from a number of operational changes. This use of the models is essential in the Feasibility Study. They provide the basis for determining how operating changes affect the multiple river uses.

3.4.8 Where Do Input Data Come From

There are long-established means for collecting and preparing the input data needed for the models. The data fall roughly into three categories:

- Data that are permanent
- Data that are revised annually
- Data that are revised only as needed.

Many model input data do not change over the years in a study period. In general, these are the physical characteristics of hydropower projects. Load and critical rule curves, on the other hand, are updated frequently. Appropriate revisions are made to reflect such things as current lists of resources and operating requirements. Data that are revised only as needed include such things as non-power operating requirements. If a new requirement is established, the information goes into the input program files. For example, in 1995, when fish-related flow objectives were established at McNary and Lower Granite, these were entered into the input data files.

Some data come from other government agencies. The U.S. Geological Survey collects streamflow measurements; the Natural Resources Conservation Service calculates snowpack; and the National Weather Service, Northwest River Forecast Center, develops streamflow (volume) forecasts.

As described previously, with rule curves, the output of one hydroregulation model becomes the input for another, or for a new computational run with the same model. HYDROSIM calculates rule curves that are used in many studies elsewhere, and both HYSSR and HYDROSIM are used to develop new operating requirements that are input into HYDREG in developing rule curves under the PNCA.

3.5 A Closeup of the Columbia River Models

The hydroregulation models are similar in many ways. They are all sequential streamflow routing models that simulate the same basic physics, the continuity equation. Each operates over a year that is divided into 14 periods. Each month is a period identified with the three letters capitalized. April and August are divided into two periods because stream flows vary greatly from the first half to the second half of these months. April 1-15 is identified as APR 1, April 16-30 is identified as APR 2, August 1-15 is identified as AUG 1 and August 16-31 is identified as AUG 2. So, the 14 periods from 1 August through 31 July are AUG 1, AUG 2, SEP, OCT, NOV, DEC, JAN, FEB, MAR, APR 1, APR 2, MAY, JUN and JUL.

All three models are written in a computer language called FORTRAN. The models all assume that water released at the uppermost project on the river during a specific period will reach the ocean during the same period, if not retained in storage downstream.

3.5.1 Hydro System Seasonal Regulation Program (HYSSR)

HYSSR is the oldest model in the region and has been updated with all current logic. It was written to analyze the Columbia River System, and is capable of simulating the region's hydropower and flood control operations as they are to be carried out under terms of the Columbia River Treaty between the United States and Canada, and the PNCA. It also accounts for all other non-power operating requirements.

The Corps uses a separate model called Streamflow Synthesis and Reservoir Regulation (SSARR) for its flood control operations and daily river forecasting. (SSARR also develops the flood control rule curves used in the three hydroregulation models.)

HYSSR can be used in one of several single-objective modes or in a combination of modes. For example, in the "Fixed Rule-Curve Level" mode, the user specifies the rule curve to which each storage project will be operated. There are seven rule curves from which to choose: the flood control (upper) rule curve; the energy content curve; the first, second, third, or fourth year critical rule curves; and empty. Flows and power generation are computed based on the rule curve specified.

HYSSR is often used to model target flows. In the "Meet Target Stream Flows" mode, the user specifies the target streamflows at control points on the river, along with the reservoirs that are to be used for flow augmentation. The model will attempt to meet these targets, starting at the uppermost control point in the basin and proceeding downstream. Selected storage projects upstream of a control point will be drafted proportionately to meet the desired target.

In all modes, the model checks the operating requirements at each project. That means the model is programmed to look at all operating limits and alert the user if a simulation shows operations would be outside those bounds.

HYSSR is used to support several annual studies, including the region's reservoir refill studies. The PNCA planning goal is to generate secondary energy only to the extent that there is a 95 percent confidence those reservoirs will refill. Analysts use HYSSR to determine whether planned operations will meet that goal in any given operating year by running simulations that span the 60 years of streamflow records.

Other studies for which HYSSR is used include: modification of flood control operations, analysis of major rehabilitation of projects, evaluation of the potential impacts of revised irrigation depletion levels, and Endangered Species Act (ESA) consultation modeling.

3.5.2 Hydro Simulator Program

Hydro Simulator Program (HYDROSIM) was written to replace two of BPA's earlier hydroregulation programs that could not share data with some of the agency's new power marketing and economic models, in particular the System Analysis Model (SAM). HYDROSIM incorporated the hydroregulation code used in SAM so data files can be easily interchanged between the models.

HYDROSIM models operations of the Pacific Northwest hydropower system. HYDROSIM can be used to determine critical rule curves and the availability of firm energy, or to examine operations under other historical streamflow conditions.

In its "Proportional Draft" mode, HYDROSIM simulates operations of the reservoirs under the PNCA. The program begins the simulation by drawing system reservoirs down to energy content curves. (This curve defines rights and obligations that the reservoir owner and downstream projects have for the use of storage under the PNCA.) Typically, water below the "firm drafting rights" elevation cannot be used. However, if the simulated system is unable to meet the system's firm load, a user option allows all reservoirs to be drafted through the critical rule curves until the firm load is met, or until the coordinated system goes empty or meets other limiting constraints.

Critical period planning is required by the PNCA. The critical period is the portion of the historical 60-year streamflow record that would produce the least amount of energy, with all reservoirs drafted from full to empty. This energy value is called the hydropower system's Firm Energy Load Carrying Capability (FELCC). The hydroregulation computer studies produce rule curves that define reservoir elevations that must be maintained to ensure firm energy requirements can be met under the most adverse historical streamflow conditions.

In recent years, the critical period has been based on the 42-month interval from September 1, 1936, through February 29, 1937. This is often referred to as the 4-year critical period. A critical rule curve is derived for each year of the 4 years; they are called Critical Rule Curves 1, 2, 3, and 4.

In HYDROSIM's "Fixed" mode, each period's operation for all or some of the reservoirs is specified in advance by the modeler. Storage at each reservoir will be drafted or filled as specified (unless constrained by physical or operational limits). The program begins at the most upstream project and proceeds downstream, setting operation at each plant based on the user-specified operating mode. After the operation is set, the program calculates flows and resulting energy generation.

Most studies use a combination of fixed mode and proportional draft. Some projects are fixed, and others are free to draft among rule curves.

3.5.3 PNCA Hydro Regulator Model

The NWPP model sets the regulations for coordinated operation of the region's hydroelectric system. A Hydro Regulator Model (HYDREG) takes the individual operating rights and requirements from the region's project owners and blends them into an operating regimen known as the Actual Energy Regulation (AER).

HYDREG was written to guide the coordinated operation of the Northwest hydropower system as directed by the PNCA. It aims to optimize power production while fulfilling all project and system non-power requirements. It is run as often as weekly during the course of the operating year to produce the AER.

The AER determines the energy capability of each project, each party to the PNCA, and of the coordinated system as a whole. The AER also provides the draft point at each reservoir that serves as the basis for rights and obligations among upstream and downstream parties during actual operations.

There are three components or processes in the model. The driving function is to regulate the reservoirs; that is, to determine the desired reservoir contents at the end of each of the 14 periods, based on reservoir rule curves and power loads. (HYDREG reports reservoir contents, which are derived from elevations.) The second process simulates the operation of individual projects. This process successively operates each hydropower plant and calculates discharge and forebay elevations, and flow reductions for fish spill and bypass. A third process computes the energy generation and peak capability at each hydropower project.

HYDREG supports many studies in the region. It is used to develop the NWPP Operating Program for the PNCA members and for the Pool as a whole. (Not all utilities in the Pool are parties to the PNCA.) It calculates the FELCC for the coordinated system and for each utility within the system, and it determines what are known as "headwater benefits," the payments downstream beneficiaries make to storage project owners. HYDREG also calculates each party's interchange rights and obligations under the PNCA. These are sales and exchanges among utilities that keep the coordinated system operating most efficiently.

3.6 From Data to Decisions

The output of a hydroregulation model is numbers. There are streamflows, expressed in m^3/s (cfs); reservoir elevations, given as feet above mean sea level (msl); reservoir contents, represented in either khm [thousand acre feet (KAF)] or khm [thousand second-foot days (ksfd)]; power generation in MW; and spill, expressed in m^3/s (cfs). Data are presented by project and for the total system.

In general, there are three types of studies: continuous, refill, and critical period. Each of these studies answers a different kind of question or set of questions about system operations.

3.6.1 The Continuous Study

The continuous study gives planners an opportunity to look at what would happen on today's system of hydropower projects under a typical long-term sequence of streamflow conditions, such as the

60-year historical period from August 1928 to July 1989. The model begins its simulation on August 1, 1928, with all reservoirs at predetermined elevations and with a prescribed set of rule curves or operating criteria for the upcoming year. It then sequentially calculates the flows and reservoir elevations that would result for each project on the river for each period in that year.

At the end of the 12-month (14-period) calculation, the study continues, modeling system operations using the July 31, 1929, reservoir elevations to begin the subsequent operating year. And so the analysis goes over 60 years, with the final elevations at the end of each operating year becoming the starting elevations for the upcoming year. This is the type of study used to determine the critical period, which is the sequence of months in the historical streamflow records that would produce the least water for power generation.

3.6.1.1 Adjusting Operations

A primary use of the continuous study is to determine the impacts of a specific operating change. For example, a proposal may be made to keep a certain reservoir full for an extra month during each year to lengthen the recreation season. Instead of drawdown beginning in September, it would begin in October. A continuous study can be run to simulate how that change in operation would affect streamflows and elevations at other projects on the river over a 60-year period. The study will yield data that can be used to demonstrate the types and magnitude of impacts that delaying drawdown at this project would have on other aspects of the hydropower system.

With this long-term view, planners are able to determine whether an operating change that looks feasible in the first 2 or 3 years has a fatal flaw at some point in the future. A set of operations geared to meet a particular flow objective might not strain the system in the first or second year. But analysis of a 60-year continuous study could show that in 5, 6, or 10 years, storage reservoirs are depleted, leaving boat ramps and recreation areas stranded, crops withering in dry fields, and electrical energy production greatly reduced.

3.6.1.2 Evaluating Resources

A continuous study can also help judge if and where to install a new hydropower generating unit. A computer run is made for a "base condition," that is, the way the system operates without the proposed generator. Then a run is made that includes the new unit. With 60 years of operation simulated by computer, planners can determine how much energy the new generator could be expected to produce and whether historical water conditions suggest the installation would be viable.

The analysis will also show whether the addition of the new project will increase the FELCC output of other projects in the system, which could be the case if the new project has seasonal storage. Additional studies can be made with varying dam heights, more or fewer generating units, or different project locations to see where it would be of the most benefit.

The continuous study can help to point out the tradeoffs that exist with any new operating scenario on a multi-use system. And it is a mechanism to test a potential operating decision. If boaters on one lake have a longer season, what would this mean next spring for fish downstream? Would a boost in flow help this year's migrating fish at the expense of the smolts 5 years from now? If BPA sells a large quantity of secondary energy next year, will there be enough power to meet firm loads in the following year?

The continuous study also provides information to answer economic questions. If a new generator is installed at an existing powerhouse on the lower Columbia, how much water can be anticipated to fuel its operation? How much power would be available for sale? What percentage of the time could it be expected to operate efficiently given historical water conditions? These are real-life questions the region's power planners and water managers grapple with continually, and the computer simulations help provide the flows and elevations to assess these questions.

3.6.2 The Refill (Non-continuous) Study

Using historical streamflow records, hydroregulation models simulate the likelihood reservoirs will refill over a year of operations. Refill is important for a number of reasons, but in particular, it is the region's hedge against dry years in the future. The amount of snow and rainfall is anybody's guess before winter begins, so it is prudent to have as much water on hand in the reservoirs as possible.

The 60-year refill study is actually 60 separate one-year studies. The reservoirs are set at the beginning of the study, August 1, 1928, to the elevations shown in the AER for July 31 of the preceding operating year. Operations are then simulated using the 1928-29 streamflow record. The reservoirs are reset to the same elevation again at the beginning of the next year in the historical sequence (the 1929-30 streamflow record). The simulation is repeated, using the historical streamflow records for each of the remaining 58 years. This gives planners the opportunity to look at how 60 different water conditions would play out on today's Columbia River hydropower system.

A non-continuous refill study can also be conducted with the elevations set at some level other than full. For example, a study may be run at mid-year to test the refill probability through the rest of the operating year. The beginning elevation is set to match the way a project has actually been operated during the first part of the year. The simulation tests 60 different historical streamflow sequences for the remainder of the year.

Under the PNCA, system operations are planned so there is an acceptable probability reservoirs will refill. The Corps uses its HYSSR model to run the annual 60-year PNCA Refill Regulation to assure that the operating rule curves developed under the PNCA have a 95 percent probability of refilling reservoirs by July 31. This refill regulation evaluates July 31 refill based on both full and observing the salmon Biological Opinion end-of-August draft limits.

The Refill Regulation is used to verify that PNCA operations have an acceptable probability of refill, and it is used to devise future operating rule curves. From the test, the Corps calculates the Assured Refill Curve for the following year. This curve will guide operations during the fixed drawdown period (late summer and fall) when the volume of the next spring runoff is unknown.

While refill is the primary use of this study, there are other uses for the non-continuous analysis. Since the reservoirs start each contract year at the same level, it is a way to examine 60 individual water years for many purposes, such as projecting the amount of energy that could be produced given the current level of system reservoirs.

3.6.3 The Critical Period Study

Critical period planning defines how much hydropower system energy should be considered firm. Hydroregulation models are used to generate the rule curves, which govern critical period operations, and to define FELCC of the system. These types of studies are run in continuous mode.

The NWPP uses HYDREG to determine the critical period rule curves and FELCC that are used to operate the system under the PNCA. BPA uses HYDROSIM for critical period studies to plan resource acquisitions and to determine the United States' benefits from Canadian Treaty reservoirs. Some of this data also goes into calculating rates and projecting revenues.

The critical rule curves are developed by simulating system operations using the streamflows that were available in the 42-month period from September 1928 to February 1932. This calculation also yields the system's FELCC, that is, how much energy the coordinated system can be expected to generate under these adverse streamflow conditions. The NWPP's hydroregulation allocates FELCC to the members of the PNCA, according to the projects they own and operate, and based on other contract provisions. In recent years the PNCA studies indicate that the critical period has changed to the sequence from September 1936 to April 1937.

In a critical period study, the model takes the initial storage content (full) for each reservoir and simulates the operation for each period through the first operating year, using 1928-29 water. The reservoir content at the end of the first operating year is the beginning content for the next year, and so forth. A critical rule curve is plotted using the end-of-period reservoir content numbers. This first critical rule curve is known as Critical Rule Curve (CRC) 1.

The reservoir content at the end of the first year of the critical period becomes the beginning content for the second year. The model simulates another year of operations, and the reservoir contents at the end of the 14 periods are plotted as CRC2. The study continues through the 42-month critical period. The final result is four critical rule curves. CRC4 will indicate that all reservoirs are empty at the end of the critical period, February 1932.

Planners determine how much power can be generated if all of the reservoirs are drafted to CRC1, CRC2, CRC3, and CRC4, by converting the plant discharge to megawatts. This type of study is particularly important for BPA in determining how much firm and secondary energy can be produced and sold from the Federal hydropower system.

Critical period planning is premised on unusually low water conditions. During most years, there is more water in the system than the critical rule curves reflect. Consequently, BPA runs analyses that look at many ways to take advantage of water conditions that are more likely to occur.

3.6.4 Modeling Alternative Measures

All of the hydroregulation models' data can be modified, using variables in almost infinite combinations, to create different operating scenarios. For example, load growth can be held constant in a long-term analysis or a study can be run using a low-, medium-, or high-growth forecast. In some studies, a project or group of projects might be input as having a fixed operation in order to determine how the rest of the hydropower system would compensate. These variations in operating strategy usually do not mean changing the program, but mostly only require input data changes. The models are designed to accommodate them effectively.

4. Alternative Descriptions

4.1 General

4.1.1 General Description of Alternatives

This study investigated drawing down the four lower Snake River dams with different Columbia River and Snake River flow augmentation scenarios. The four dams are Lower Granite, Little Goose, Lower Monumental, and Ice Harbor. These measures are denoted as the "A" series of alternatives. In these alternatives Libby would still provide higher outflows for sturgeon. Below and in Table 4-1 is a brief description of these alternatives followed by the detailed hydroregulation specification beginning in Section 4.2.

- The Base Condition or Alternative **A1** is a continuous study of the system operations under the Salmon and Sturgeon Biological Opinion.
- Alternative **A2** is a continuous study of the system operations under the Salmon and Sturgeon Biological Opinion without drawdown on the lower Snake River or John Day reservoirs. This alternative relies on fish transportation as the primary method for fish passage and assumes the current level of development of fish facilities. Also, this alternative eliminates fish spill at fish transportation dams—Lower Granite, Little Goose, Lower Monumental, and McNary.
- Alternative **A3** is a continuous study of the system operations under a scenario where the Base Condition is adjusted for the drawdown of all four lower Snake River dams to natural river levels. Columbia River and Snake River flow augmentation would remain unchanged.
- Alternative **A5** is a continuous study of the system operations under a scenario where the Base Condition is adjusted for the drawdown of all four lower Snake River dams to natural river level and to remove flow augmentation on the lower Snake River at Lower Granite including the 52.7 khm (427 KAF) from the upper Snake River.
- Alternative **A6a** is a continuous study of the system operation under a scenario where the Base Condition is adjusted to increase the upper Snake River flow augmentation 123.3 khm [1 million-acre-feet (MAF)], to 176 khm (1,427 KAF) total upper Snake flow augmentation. The lower Snake River or John Day dams would not be drawn down. Also, spring and summer Lower Granite flow objectives and June 30 reservoir refill priorities are adjusted from the Base Condition.
- Alternative **A6b** is a continuous study of the system operation under a scenario where the Base Condition is adjusted to incorporate no upper Snake River flow augmentation. The 427 KAF flow augmentation in the Base Condition is eliminated. The lower Snake River or John Day dams would not be drawn down. Again as in Alternative A6a, the spring and summer Lower Granite flow objectives and June 30 reservoir refill priorities are adjusted from the Base Condition.

A feasibility study on drawing down the John Day project is also being conducted. For this study two alternatives are being investigated. They include operating the John Day project at natural river levels or at spillway crest. The John Day operation to natural river level is denoted as series "B" (Table 4-1) and the operation to spillway crest is denoted as series "C".

Table 4-1. General Description of Alternatives

Alternative	Flow Augmentation				Project Drawn Down		
			Upper Snake				John Day at Spillway
	Columbia	Snake	(khm)	(KAF)	Lower Snake	John Day at Natural River	
A1	Yes	Yes	52.7	427	No	No	No
A2[1/]	Yes	Yes	52.7	427	No	No	No
A3	Yes	Yes	52.7	427	Yes	No	No
A5	Yes	No			Yes	No	No
A6a	Yes	Yes	176.0	1,427	No	No	No
A6b	Yes	Yes			No	No	No
B1	Yes	Yes	52.7	427	Yes	Yes	No
B2	No	No			Yes	Yes	No
C1	Yes	Yes	52.7	427	Yes	No	Yes
C2	No	No	0		Yes	No	Yes

[1/] A2 has no spill at Lower Granite, Little Goose, Lower Monumental, and McNary.

Below is a brief description of these alternatives followed by the detailed hydroregulation specification. In the "A" series above, John Day was operated according to the Salmon Biological Opinion. The results of this study will not be used to make a decision regarding drawdown at John Day. In these alternatives Libby would still provide higher outflows for sturgeon. Below and in Table 4-1 is a brief description of these alternatives followed by the detailed hydroregulation specification beginning in Section 4.8.

- **Alternative B1:** A continuous study of the system operations under a scenario where the Base Condition is adjusted only for drawdown of all four lower Snake River dams to natural river levels and John Day is operated at natural river level. Flow augmentation on the Columbia and Snake Rivers would remain unchanged.

- **Alternative B2:** The Base Condition is adjusted for drawdown of all four lower Snake River dams to natural river levels and John Day is operated at natural river level. Flow augmentation on the Columbia River and Snake River are removed, thereby freeing up the reservoir operation for power purposes much of the time. Juvenile bypass spill and 1 percent peak operation is retained.

- **Alternative C1:** A continuous study of the system operations under a scenario where the Base Condition is adjusted only for drawdown of all four lower Snake River dams to natural river levels and John Day is operated at spillway crest. Flow augmentation on the Columbia River and Snake River would remain unchanged.

- **Alternative C2:** The system operates under a scenario where the Base Condition is adjusted only for drawdown of all four lower Snake River dams to natural river levels and John Day operated at spillway crest. Flow augmentation on the Columbia River and Snake River would be removed, thereby freeing up the reservoir operations for power purposes much of the time. Juvenile bypass spill and 1 percent peak operation is retained.

4.1.2 Hydroregulation Study Steps

The Corps performed one regulation analysis for the base condition and each alternative. The regulation included all the power and non-power requirements described in the following sections.

BPA ran two regulations, an AER Step and an Operational Step. The AER Step is used to determine the project minimum elevations (or maximum draft) using load equal to FELCC and unlimited secondary market. Minimum elevations from the AER Step were input into the Operational Step. The Operational Step used PNCA submitted loads and a limited secondary market. The Operation Step was modeled the same as the AER step, except as specifically addressed below.

4.1.3 Stream Flows

4.1.3.1 Modified Stream Flows

The 60 years of modified stream flows used are from *Modified Streamflows 1990 Level of Irrigation*, dated July 1993. They contain the 1928-89 stream flow record adjusted for the 1990 level irrigation withdrawals. Adjustments have been made to these 1990 level modified stream flows due to the BOR's updated Grand Coulee pumping schedule for the Columbia Basin Project. This pumping schedule is included in the BOR February 1, 1996 preliminary PNCA data submittal. BPA used 50 years of stream flow records.

4.1.3.2 Continuous Stream Flow Mode

To measure the impact to power production, a hydroregulation in continuous mode was used to simulate the base condition and alternatives investigated. The study begins on 1 August 1928 and ends on 31 July 1988, a 60-year study. BPA ran through 31 July 1978, a 50-year study.

4.1.4 Study Area

4.1.4.1 Regulated Hydroelectric Projects

The Western System Coordinating Council (WSCC) is the largest electrical reliability council in North America encompassing the entire states of Washington, Oregon, Idaho, California, Nevada, Utah, Wyoming, Arizona and parts of Montana, Nebraska, New Mexico, and Texas, as well as British Columbia and Alberta in Canada. In Canada the WSCC includes British Columbia and Alberta. The WSCC is then further subdivided into four general load areas: Northwest Power Pool, Rocky Mountain Power Pool, Arizona-New Mexico Power Pool, and California-Southern Nevada Power Pool.

In 1964 the PNCA was signed by a subgroup of utilities in the NWPP area. This subregion is used as the study area and defines the projects modeled in the hydroregulation. The study area consists of Washington, Oregon, Idaho, and Montana west of the continental divide, and that area within the Columbia Basin in British Columbia and Alberta, Canada.

Hydroelectric projects within the study area that are coordinated with the system load are modeled as regulated hydro projects. Control points were added in locations where flow objectives are placed in the system or where minimum or maximum flows are needed. See Table 4-2 for a complete list of regulated

Table 4-2. Regulated Hydroelectric Projects and Control Points

White River	Kerr	Priest Rapids
Timothy	Thompson Falls	Brownlee
Clackamas	Noxon	Oxbow
Upper Baker	Cabinet Gorge	Hells Canyon
Lower Baker	Priest Lake	Dworshak
Ross	Albeni Falls	Lower Granite
Diablo	Box Canyon	Little Goose
Gorge	Boundary	Lower Monumental
Cushman No 1	Seven Mile	Ice Harbor
Cushman No 2	Waneta	McNary
Alder	Upper Falls	John Day
La Grande	Monroe Street	Round Butte
Libby	Nine Mile	Pelton & Rereg
Bonners Ferry	Long Lake	The Dalles
Duncan	Little Falls	Bonneville
Corra Linn	Grand Coulee	Swift No 1
Kootenay Plants	Chief Joseph	Swift No 2
Canal Plant	Wells	Yale
Brilliant	Chelan	Merwin
Mica	Rocky Reach	Mossyrock
Revelstoke	Rock Island	Mayfield
Arrow	Wanapum	Hungry Horse

hydropower projects and control points used in this study. Oak Grove, North Fork, Faraday, River Mill are modeled as the Clackamas project.

4.1.4.2 Independent Hydroelectric Projects

Of the hydroelectric projects found in the Pacific Northwest and the study area there is a subset of plants which are not coordinated within the region. These plants have a fixed generation output and are usually operated on fixed-rule curves or are run-of-river type projects. See Table 4-3 for a list of Independent hydropower projects used to meet the system load of the Pacific Northwest.

4.2 The Base Condition or Alternative A1

The Base Condition is a description of how the PNW reservoir system would be operated, assuming the current operating requirements. The base condition was developed during the summer of 1997 and reflects the proposed operations for endangered fish species covered under the Endangered Species Act (ESA) and described in 1) NMFS Biological Opinion of March 2, 1995 titled *Reinitiation of Consultation on the 1994-98 Operation of the Federal Columbia River Power System and Juvenile Transportation Program in 1995 and Future Years* (Salmon Biological Opinion); 2) *USFWS Biological Opinion of March 1, 1995* (Sturgeon Biological Opinion); and 3) the Corps of Engineers Record of Decision (ROD) titled *Columbia River System Operation Review Selection of a System Operation Strategy,* signed February 20, 1997.

Table 4-3. Hydropower Independent Projects

Jackson	Dexter	Walterville
Klamath Lake	Cougar	TW Sullivan
John Boyle	Green Peter	Stone Creek
Iron Gate	Foster	Bullrun
Lost Creek	Detroit	Cowlitz Falls
Copco 1&2	Big Cliff	Meyers Falls
Fall Creek	Carmen Smith	Palisades
Hills Creek	Trailbridge	Anderson Ranch
Lookout Point	Leaburg	Electron
Nooksack	Snoqualmie 1&2	Prospect 14
Eagle Point	Lemolo 1&2	Clearwater 182
Toketee	Fish Creek	Slide Creek
Soda Springs	Condit	Powerdale
Naches	Naches Drop	Big Fork
Bend	Cline Falls	Wallowa Falls
Cedar Falls	Newhalem	Black Canyon
Boise R. Diversion	Minidoka	Roza
Chandler	Packwood	

4.2.1 System Demand

4.2.1.1 Loads

The system demand or load was developed from the Operating Year 1997 Critical Period study run by the NWPP. The NWPP study resulted in a 1-year critical period (September 1, 1936 through April 30, 1937) where the generation during the critical period becomes the firm energy load carrying capability or FELCC. Outside the critical period, in May, June, July, and August, FELCC will come from the PNCA Final Regulation. Only one year of FELCC values are used for all water conditions. Sixty years of FELCC was developed by adding Hydropower Independent generation (see Table 4-4) from 1936-37 to compute system total generation. Then, the system total generation will be reduced by 60 years of hydropower independent generation to produce 60 years of FELCC. These 60 years of loads were used as input to the HYSSR model.

This study reflects coordination between PNCA parties in meeting PNCA FELCC. Therefore, generation from projects owned by non-PNCA parties (Brownlee, Oxbow and Hells Canyon) were not used to meet PNCA FELCC in these studies.

BPA produced 50 years of loads and use the above requirements in their AER Step.

4.2.1.2 Secondary Market

This study has a secondary market limit of 9,000 average megawatts (aMW). The transfer capability of secondary generation outside the study area to Northern California is 7,500 MW, to Nevada is 190 MW, to Southern Idaho is 1,200 MW, and to Eastern Montana is 1,200 MW. BPA operated the AER step to an unlimited secondary market.

Table 4-4. Hydropower Independent Generation—aMW

	AUG1	AUG 2	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR1	APR 2	MAY	JUN	JUL
28-29	667	640	667	777	822	678	644	537	667	746	792	1087	1078	774
29-30	648	600	585	567	545	853	612	1016	715	726	714	790	764	699
30-31	605	575	604	608	674	570	632	604	680	903	684	790	698	616
31-32	531	505	557	611	750	638	769	536	1181	1085	1107	1252	1137	790
32-33	676	634	645	745	1027	852	859	543	729	772	860	1209	1421	972
33-34	757	706	758	866	905	1031	1128	737	755	726	695	711	576	643
34-35	485	479	481	748	1112	1025	868	765	693	807	883	1038	958	690
35-36	600	571	565	648	676	590	1074	632	785	848	1019	1282	1081	768
36-37	644	612	660	625	568	639	496	533	746	1001	1059	1264	1322	826
37-38	650	618	647	760	1101	1089	1070	707	903	976	1294	1360	1017	737
38-39	667	653	689	713	919	917	858	694	860	916	931	1050	890	817
39-40	642	594	618	701	686	831	723	895	1011	915	828	829	664	668
40-41	599	545	611	672	826	778	772	621	599	589	570	756	670	595
41-42	581	563	666	821	921	1094	795	705	623	757	764	919	933	743
42-43	648	609	652	646	1164	1195	1094	917	982	1341	1301	1187	1272	873
43-44	753	739	766	843	940	843	704	676	675	740	759	850	876	767
44-45	642	607	604	641	819	630	875	976	758	849	1049	1428	981	716
45-46	615	612	758	760	1070	1156	1110	759	910	954	1183	1329	1201	866
46-47	707	640	697	857	1135	1208	901	895	856	1063	1027	937	1012	800
47-48	681	643	694	1050	1237	896	1095	776	782	840	1043	1386	1367	852
48-49	738	696	741	885	1003	1024	618	766	1036	1119	1300	1504	1112	885
49-50	715	658	698	870	967	836	967	905	1208	1243	1248	1338	1373	1022
50-51	810	806	792	1093	1354	1303	1239	1207	1029	1224	1157	1272	950	831
51-52	740	735	798	1057	1137	1110	873	981	894	1264	1304	1386	1248	931
52-53	729	716	785	761	757	711	1254	1194	879	838	1005	1378	1329	964
53-54	813	788	810	892	1244	1273	1156	1071	896	1239	1164	1214	1294	1002
54-55	846	829	861	922	982	862	791	725	694	838	816	1229	1336	1028
55-56	759	690	739	976	1271	1284	1243	846	982	1162	1357	1466	1396	988
56-57	796	788	858	1030	1145	1244	824	859	1212	1303	1108	1259	971	817
57-58	665	655	776	838	944	1165	1150	1168	830	854	1206	1259	1177	850
58-59	731	685	768	844	1214	1072	1200	838	843	976	945	1135	970	825
59-60	675	642	887	1016	986	829	687	859	1001	1199	1043	1354	1101	763
60-61	674	645	705	798	1148	954	876	1216	1130	946	873	1170	1006	713
61-62	620	578	657	823	1013	1079	957	763	701	1159	1195	1222	1011	799
62-63	724	674	701	1003	1193	1138	758	1034	810	1034	976	1247	843	771
63-64	647	594	677	768	1147	930	1055	773	768	1009	983	1206	1390	925
64-65	760	742	802	836	974	1300	1256	991	952	940	1078	1135	1004	792
65-66	768	747	745	807	964	803	1012	672	823	1124	1016	1144	923	830
66-67	645	591	647	737	998	1095	1108	863	791	866	851	1126	1147	798
67-68	648	647	646	926	934	914	997	1074	881	681	694	874	819	757
68-69	600	610	807	886	1259	1102	1090	743	791	948	1046	1442	1206	757
69-70	662	613	683	854	905	937	1169	931	844	898	920	1080	934	766
70-71	641	583	675	810	1139	1042	1260	1063	1133	1195	1056	1427	1354	947
71-72	807	770	880	921	1205	1138	1246	1225	1546	1258	1174	1380	1194	987
72-73	800	785	888	855	951	1111	1132	749	714	662	717	886	771	751
73-74	606	568	640	763	1300	1267	1233	949	1159	1333	1181	1347	1378	931
74-75	825	779	778	751	897	1149	1201	899	1004	902	950	1325	1226	973
75-76	771	758	780	957	1211	1286	1290	932	883	969	1032	1229	1042	926
76-77	831	824	776	762	824	663	602	572	608	617	635	872	711	656
77-78	554	534	572	694	1200	1213	990	741	740	759	813	973	806	679
78-79	642	652	793	704	838	906	727	782	984	942	1038	1151	805	694
79-80	580	579	653	666	794	941	1048	771	784	816	979	965	821	691
80-81	573	562	676	621	908	1120	776	808	717	689	747	833	948	705
81-82	620	569	622	751	917	1126	966	1196	1100	1031	1089	1149	1077	854
82-83	714	697	811	914	1042	1191	1229	1021	1114	1103	989	1165	1096	915
83-84	707	769	825	796	1154	1084	1244	948	1100	1138	1061	1286	1268	866
84-85	710	723	864	916	1252	972	847	682	691	980	1062	1155	1053	766
85-86	649	596	737	862	1058	815	998	1138	1211	972	964	1070	862	705
86-87	633	611	777	800	1132	865	887	797	869	759	800	888	724	671
87-88	601	544	576	545	590	832	811	670	753	913	857	1039	978	675
MAX.	846	829	888	1093	1354	1303	1290	1225	1546	1341	1357	1504	1421	1028
MED.	666	641	700	804	992	1024	978	823	850	944	1010	1178	1015	795
AVE.	680	653	714	806	997	987	964	849	884	958	983	1151	1043	807
MIN.	485	479	481	545	545	570	496	533	599	589	570	711	576	595

4.2.2 Rule Curves

4.2.2.1 Flood Control Rule Curves

This study used Upper Rule Curves (URC) for flood control, calculated by using observed runoff volume. The upper rule curve file was created for the February 1, 1996 PNCA Data Submittal by the Corps. The data incorporates shifting system flood control from the Dworshak and Brownlee projects, when the April-July runoff volume forecasts are less than 394.7 khm (3.2 MAF) and 715.4 khm (5.8 MAF), respectively, to Grand Coulee. The flood control at Canadian Treaty projects incorporates the 256.6 khm (2.08 MAF) Mica and 629.1 khm (5.1 MAF) Arrow flood control storage allocation. Flood control will take precedence over all non-power requirements, except Libby where the flood control elevations may be exceeded to meet the International Joint Commission (IJC) 1938 Order at Kootenay Lake. BPA used flood control calculated by the Corps using forecasted volume runoff based on Kuehl Moffitt Report dated July 1986.

4.2.2.2 Variable Energy Content and Assured Refill Curves

Variable Energy Content Curves (VECCs) and Assured Refill Curve (ARC) are used to guide the operation in wet water years and are calculated using the Operating Year 1996-97 Power Discharge Requirements (PDRs), distribution factors, and forecast errors which were used in PNCA planning. Canadian Treaty project operations were determined using the 1996-97 Assured Operating Plan (AOP97) PDR and the Arrow Total method. The runoff volume forecast for all projects is based on actual runoff. The VECC at Grand Coulee was limited to elevation 365.8 m (1,220 ft) in all periods due to the Gifford-Inchelium Ferry that cannot operate below this elevation.

BPA used volume forecasts based on the Kuehl Moffitt Report dated July 1986. Although VECC lower limits were eliminated from OY97 refill studies, in the Operational Step, a lower limit of 379.5 m (1,245 ft) in January, 371.9 m (1,220 ft) February through April, 378.0 m (1,240 ft) in May, and 391.7 m (1,285 ft) in June at Coulee was used in calculating the VECC during period in which the system is generating surplus energy. The VECCs for the Federal projects were based on the Kuehl Moffitt volume forecasts. The Canadian VECC were based on historical volumes.

4.2.2.3 Critical Rule Curves

CRCs are used to guide the operations in critical water years in accordance with PNCA and were developed during PNCA planning and published in the Final Regulation. The first year critical rule curve, CRC1, used in this study is the CRC1 from the Operating Year 1996-97 Final Regulation. The CRC2 used in this study is the CRC3 from Operating year 1994-95 and the CRC3 used in this study is the CRC4 from the Operating Year 1993-94. There is no CRC4 due to the one-year critical period so CRC4 was set to empty. Reservoirs will draft proportionally between these rule curves when the system load is not met.

4.2.3 Project Operations

4.2.3.1 Reservoir Storage Initialization

Storage reservoirs were initialized to full on 1 August 1928, with the following exceptions. Mica usually fills in August so it was initialized to the July Mica target content of 87.1 khm (356.2 ksfd). Libby, Hungry Horse, Grand Coulee, and Dworshak are expected to augment for downstream flow objectives at McNary and Lower Granite down to their draft limits in July so they were initialized to

elevation 746.5 m (2,449 ft) [558.0 khm (2,281.3 ksfd)], 1,082.0 m (3,550 ft) [349.2 khm (1,427.7 ksfd), 391.7 m (1,285.0 ft) [591.2 khm (2,417.1 ksfd)] and 463.3 m (1,520.0 ft) [96.9 khm (396.0 ksfd)], respectively. John Day is operated within .5 m (1.5 ft) of elevation 80.0 m (262.5 ft) through July so it was initialized to elevation 80.0 m (262.5 ft) [31.2 khm (127.7 ksfd)]. In the IJC 1938 Order, there were maximum lake levels at Corra Linn set for July, so it was initialized to elevation 531.4 m (1,743.32 ft) [55.5 khm (226.7 ksfd)]. Brownlee was initialized to elevation 630.6 m (2,069.0 ft) [106.7 khm (436.3 ksfd)] in July.

4.2.3.2 Non-Power Requirements

All projects followed the non-power requirements from the PNCA plant data book, updated September 30, 1996, or which were submitted for the Operating Year 1997 PNCA planning process on February 1, 1996, except as noted within.

4.2.3.3 Canadian Treaty Storage Operation

The Columbia River Treaty prescribes the method for determining the Canadian storage operation and the Canadian entitlement for such operation. This storage operation is determined 6 years advance in assured operating plans (AOPS) and modified to achieve mutual benefit in detailed operating plans. The Canadian Treaty storage projects, Mica, Duncan, and Arrow were operated to the AOP 1996-97 operations including changes agreed to by the Entities as described in the 1996-97 Detailed Operating Plan (DOP97). The Canadian Treaty projects were fixed to the operation resulting from the 60-year DOP97 Treaty Storage Regulation. This 60-year operation was prepared by the Corps for use in the 1996-97 PNCA studies. The regulation incorporates the Arrow Total method of computing VECC. BPA used a 50-year DOP Treaty Storage Regulation that was adopted for PNCA. Mica data logic in the HYDROSIM program was turned off. Mica's minimum storage content was reset to 0.0 khm (0.0 ksfd) so that drafting below 622.2 khm (2,543.8 ksfd)(normal minimum content) can occur.

4.2.3.4 Libby Project Operation

The Libby project operation was consistent with the Sturgeon and Salmon Biological Opinion. During September through December, Libby was operated to meet FELCC down to the December 31 flood control elevation of 734.9 m (2,411.0 ft) [367.4 khm (1,502.2 ksfd)]. In January through mid-April, Libby was operated on minimum flow or flood control objectives as defined in the Salmon Biological Opinion. It should be noted that Libby can exceed URC in some periods when discharges would have forced Corra Linn Reservoir above allowable lake levels as defined in the IJC 1938 Order.

From mid-April through July Libby was operated for protection of sturgeon in all but 20 percent of the lowest observed April-September runoff volumes at Libby by supporting Bonners Ferry minimum flows. Sturgeon releases were not provided in operating years 1928-29, 1930-31, 1935-36, 1936-37, 1939-40, 1940-41, 1943-44, 1944-45, 1969-70, 1977-78, 1978-79, and 1987-88. During these years salmon releases were provided as described below. BPA used the May 1 volume forecast based on Kuehl Moffitt Report to determine the years when sturgeon releases would not be provided. Refer to the Flow Objective Table 4-9 in the OPER Step to identify the years when these flows were not provided. Sturgeon flow objectives from April 16th through April 30 were to increase flows at Libby so that Bonners Ferry flow was at 424.8 m^3/s (15,000 cfs) on May 1. From May 1 through 19, a minimum flow at Bonners Ferry of 424.8 m^3/s (15,000 cfs) was maintained.

From May 20 through June 30 sturgeon augmentation from Libby attempted to maintain a maximum flow at Bonners Ferry of 991.0 m^3/s (35,000 cfs). From July 1 through July 21 a minimum flow at Bonners Ferry of 311.5 m^3/s (11,000 cfs) was maintained. During July 22 through July 31 a minimum flow at Libby of 113.3 m^3/s (4,000 cfs) was maintained after ramping down from 311.5 m^3/s (11,000 cfs). Libby's maximum outflow from mid-April through August was equal to powerhouse hydraulic capacity without spilling.

In July, mid-August and August, Libby was operated to as low as elevation 746.5 m (2,449 ft); 743.4 m (2,439 ft); and 743.4 m (2,439 ft) [558.0 khm (2,281.3 ksfd); 504.2 khm (2,061.3 ksfd); and 504.2 khm (2,061.3 ksfd)] to contribute to flow augmentation at McNary. During years when sturgeon releases were not provided Libby supported McNary flow objective April 16 through August. During these years Libby was operated on minimum flow or flood control January through mid-April. Libby supported McNary flow objective in the last part of April, May, June, July, the first and last part of August down to elevation 737.6 m (2,420 ft); 737.6 m (2,420 ft); 743.4 m (2,439 ft); 746.5 m (2,449 ft); 743.4 m (2,439 ft); and 743.4 m (2,439 ft), respectively.

4.2.3.5 Hungry Horse Project Operation

Hungry Horse was operated to meet FELCC September through December subject to draft limits of elevation 1,076.2 m (3,531 ft); 1,074.7 m (3,526 ft); 1,073.2 m (3,521 ft); and 1,071.4 m (3,515.0 feet) [297.4 khm (1,215.7 ksfd); 284.2 khm (1,162.0 ksfd); 271.1 khm (1,108.3 ksfd); and 256.6 khm (1,049.0 ksfd)], respectively. From January through mid-April, Hungry Horse was free to operate to meet FELCC above its Biological Rule Curves objectives as defined in the Salmon Biological Opinion (Calculated according to instructions in the 1996-97 PNCA Operating Procedures). See Table 4-5. On April 30, May 31, June 30, July 31, August 15 and August 31, Hungry Horse may draft to limits of elevation 1,079.0 m (3,540 ft); 1,079.0 m (3,540 ft); 1,079.0 m (3,540 ft); 1,082.0 m (3,550 ft); 1,079.0 m (3,540 ft); and 1,079.0 m (3,540.0 ft) [(321.0 khm) 1,312.3 ksfd; (321.0 khm) 1,312.3 ksfd; (321.0 khm) 1,312.3 ksfd; (349.2 khm) 1,427.7 ksfd; (321.0 khm)1,312.3 ksfd; and (321.0 khm) 1,312.3 ksfd] by supporting McNary flow objectives. Hungry Horse was operated to support a Columbia Falls minimum flow of 99.1 m^3/s (3,500 cfs) year round and maximum flow of 127.4 m^3/s (4,500 cfs) October 15 through December 15. The reservoir storage-elevation relationship reflected 3 percent bank storage. Hungry Horse maximum outflow from mid-April through August is powerhouse hydraulic capacity plus 85 m^3/s (3,000 cfs) spill.

4.2.3.6 Albeni Falls Project Operation

Albeni Falls was operated in September to elevation 627.9 m (2,060.0 ft) [113.9 khm (465.7 ksfd)]. In October through April, Albeni Falls was operated to elevation 626.4 m (2,055.0 ft) [57.4 khm (234.7 ksfd)]. In May, Albeni Falls was operated to elevation 627.0 m (2,057.0 ft) [79.9 khm (325.7 ksfd)]. In June through August, Albeni Falls is operated to full, elevation 628.7 m (2,062.5 ft) [142.5 khm (582.4 ksfd)].

4.2.3.7 Grand Coulee Project Operation

Grand Coulee was operated to meet FELCC September through December subject to draft limits of elevation 390.1 m (1,280 ft); 390.1 m (1,280 ft); 388.6 m (1,275 ft); and 385.6 m (1,265 ft), respectively. BPA did not model these draft limits in the AER Step. In January through mid-April,

Table 4-5. 1996-97 PNCA Biological Rule Curves for Hungry Horse and Grand Coulee—ft

Year 19__	JAN	FEB	MAR	AP1	Year 19__	JAN	FEB	MAR	AP1
29	3528.8	3523.8	3519.6	3520.0	29	1271.3	1277.8	1272.4	1280.2
30	3540.5	3535.6	3531.0	3533.7	30	1290.0	1288.7	1282.2	1281.5
31	3537.7	3533.3	3529.3	3531.7	31	1290.0	1290.0	1282.9	1281.5
32	3496.2	3492.2	3496.0	3501.2	32	1208.0	1208.0	1211.4	1220.0
33	3462.5	3456.5	3452.3	3458.6	33	1208.0	1208.0	1209.3	1220.3
34	3508.2	3510.2	3513.8	3518.7	34	1208.0	1210.4	1234.9	1246.2
35	3512.4	3511.1	3507.9	3509.2	35	1208.0	1208.0	1232.6	1252.4
36	3522.2	3516.3	3511.8	3514.0	36	1211.6	1216.3	1234.1	1243.1
37	3536.4	3529.9	3523.7	3523.4	37	1290.0	1288.7	1282.2	1280.2
38	3521.8	3517.4	3514.1	3517.5	38	1208.0	1208.0	1230.5	1225.9
39	3516.5	3510.8	3509.0	3513.2	39	1265.2	1267.9	1274.4	1268.1
40	3542.0	3536.6	3533.1	3535.6	40	1290.0	1286.2	1279.2	1273.7
41	3560.0	3560.0	3555.9	3557.2	41	1289.3	1285.9	1280.0	1281.9
42	3528.7	3525.2	3520.7	3523.6	42	1208.0	1229.8	1251.3	1252.8
43	3478.4	3475.9	3474.1	3481.0	43	1208.0	1208.0	1239.1	1232.9
44	3555.3	3549.3	3543.4	3543.8	44	1289.7	1280.8	1280.8	1282.2
45	3523.8	3518.9	3513.9	3514.4	45	1249.7	1246.8	1252.3	1260.2
46	3507.3	3503.3	3501.9	3506.4	46	1208.0	1208.0	1208.0	1218.8
47	3485.9	3483.2	3483.7	3489.6	47	1208.0	1208.0	1227.7	1226.3
48	3486.4	3481.5	3477.4	3479.6	48	1208.0	1208.0	1208.0	1208.0
49	3521.5	3516.1	3511.2	3514.8	49	1208.0	1208.2	1231.2	1233.5
50	3449.0	3444.9	3444.6	3451.3	50	1208.0	1208.0	1208.0	1213.0
51	3482.2	3484.9	3484.8	3490.2	51	1208.0	1208.0	1223.4	1221.5
52	3519.8	3515.6	3511.6	3515.5	52	1208.0	1208.0	1230.4	1225.7
53	3496.8	3495.0	3491.7	3494.6	53	1208.0	1208.0	1208.0	1221.0
54	3461.4	3456.1	3452.8	3457.5	54	1208.0	1208.0	1208.0	1208.0
55	3507.0	3502.7	3498.1	3499.8	55	1208.0	1208.0	1208.0	1211.9
56	3486.7	3482.4	3479.2	3484.1	56	1208.0	1208.0	1208.0	1208.0
57	3514.3	3509.7	3506.3	3508.3	57	1208.0	1208.0	1215.9	1221.5
58	3515.4	3510.2	3506.6	3510.1	58	1208.0	1208.0	1220.4	1222.8
59	3439.6	3438.0	3436.9	3446.6	59	1208.0	1208.0	1208.0	1212.1
60	3504.6	3501.8	3503.7	3508.1	60	1208.0	1208.0	1229.3	1231.3
61	3495.5	3492.9	3492.3	3497.6	61	1208.0	1208.0	1208.0	1217.1
62	3501.7	3498.3	3494.2	3499.6	62	1208.0	1208.0	1234.7	1231.9
63	3521.9	3521.9	3520.4	3523.3	63	1215.1	1238.8	1256.8	1255.5
64	3479.7	3473.3	3467.2	3470.5	64	1208.0	1208.0	1213.5	1217.8
65	3471.0	3468.2	3464.4	3471.0	65	1208.0	1208.0	1232.0	1227.8
66	3516.0	3511.4	3507.9	3511.8	66	1208.0	1238.4	1258.8	1257.0
67	3471.3	3469.2	3466.1	3470.8	67	1208.0	1208.0	1208.0	1210.7
68	3500.2	3496.9	3498.8	3502.5	68	1208.0	1227.2	1248.8	1248.9
69	3515.9	3512.3	3508.6	3512.7	69	1208.0	1208.0	1212.1	1221.9
70	3499.1	3493.5	3488.3	3490.2	70	1215.5	1219.9	1237.6	1237.1
71	3456.1	3460.5	3460.3	3466.7	71	1208.0	1208.0	1208.0	1209.5
72	3451.2	3444.9	3451.1	3460.2	72	1208.0	1208.0	1208.0	1208.0
73	3536.0	3531.8	3527.0	3528.3	73	1272.9	1282.1	1275.0	1281.5
74	3437.6	3440.2	3441.7	3451.0	74	1208.0	1208.0	1208.0	1208.0
75	3482.3	3476.6	3471.0	3472.3	75	1208.0	1208.0	1221.9	1226.8
76	3488.9	3485.6	3482.0	3487.5	76	1208.0	1208.0	1216.4	1223.9
77	3558.7	3553.6	3548.1	3548.6	77	1285.2	1279.7	1280.4	1282.5
78	3498.0	3492.6	3490.7	3496.2	78	1208.0	1208.0	1228.0	1225.4
79	3510.9	3505.8	3503.4	3506.3	79	1279.4	1284.6	1267.5	1268.6
80	3527.9	3522.4	3517.5	3517.7	80	1208.0	1211.9	1236.0	1246.8
81	3496.0	3495.7	3497.0	3501.8	81	1208.0	1208.0	1231.4	1231.9
82	3473.5	3471.6	3471.6	3475.9	82	1208.0	1208.0	1208.3	1218.1
83	3516.9	3513.2	3512.6	3515.3	83	1208.0	1208.0	1226.2	1228.8
84	3519.4	3517.4	3515.3	3517.8	84	1208.0	1208.0	1218.8	1223.0
85	3509.3	3504.6	3500.4	3504.2	85	1230.0	1238.3	1251.0	1250.6
86	3519.5	3517.3	3520.1	3523.8	86	1208.0	1229.4	1248.7	1244.3
87	3548.0	3543.2	3542.5	3544.8	87	1289.8	1288.1	1281.7	1280.5
88	3544.9	3539.0	3534.1	3536.5	88	1290.0	1290.0	1283.1	1280.4

minimum storage values were calculated for Grand Coulee (Biological Rule Curves) which guide the reservoir to its expected April 15 URC elevation. See Table 4-5. Grand Coulee was then operated to meet FELCC above these minimum storage points. Storage releases needed for the appropriate Vernita Bar minimum flow requirement was also provided December through May. From mid-April through May, Grand Coulee was drafted to the lower of flood control or elevation 381 m (1,250 ft) to support McNary flow augmentation objectives. In June, Grand Coulee was drafted to the lower of flood control or elevation 390.1 m (1,280 ft) to support McNary flow augmentation objectives. July, mid-August and August, Grand Coulee was drafted as low as elevation 391.7 m (1,285 ft); 390.1 m (1,280.0 ft); and 390.1 m (1,280.0 ft) [591.2 khm (2,417.1 ksfd); 542.1 khm (2,216.4 ksfd); and 542.1 khm (2,216.4 ksfd)] to support McNary flow augmentation objectives. At-site the project minimum flow was equal to 849.5 m^3/s (30,000 cfs). Grand Coulee is subject to a drawdown limit of 0.5 m (1.5 ft) per day for side slope stability, but it was modeled as 0.4 m (1.3 ft) per day over an entire month.

4.2.3.8 Brownlee Project Operation

Brownlee was operated on flood control from February through April. In May the reservoir was operated to elevation 630.6 m (2,069 ft) or lower if required for flood control. In June, Brownlee was filled if necessary and maintained at elevation 633.1 m (2,077 ft). In July, the first and last part of August, the reservoir was drafted to elevation 630.6 m (2,069 ft); 624.8 m (2,050 ft); and 624.2 m (2,048 ft), respectively, for flow augmentation which includes both Idaho Power Company contribution and shaping of upper Snake water by the end of August. In September and October, the reservoir operated to elevation 624.8 m (2,050 ft) and 624.2 m (2,048 ft), respectively in anticipation of providing a maximum discharge of 254.8 m^3/s (9,000 cfs) from mid-October through November. Outflows up to 566.3 m^3/s (20,000 cfs) were allowed in October (the average of 849.5 m^3/s (30,000 cfs) in the first half and 254.8 m^3/s (9,000 cfs) in the second half of the month). Discharges higher than 254.8 m^3/s (9,000 cfs) were not allowed in November. By the end of December and January, the reservoir is operated at elevation 630.9 m (2,070 ft) and 627.9 m (2,060 ft), respectively.

4.2.3.9 Dworshak Project Operation

Dworshak operation was set on minimum flow of 36.8 m^3/s (1,300 cfs) all periods or flood control objectives as defined in the Salmon Biological Opinion, with the exception of the last part of April through August when it operates to meet Lower Granite flow augmentation objectives. Dworshak was drafted to elevation 463.3 m (1,520 ft) by August 31 to support Lower Granite flow augmentation objectives. Dworshak's outflow was limited to 396.4 m^3/s (14,000 cfs) during the flow augmentation period (mid-April through August) and was limited to 707.9 m^3/s (25,000 cfs) in all other periods for downstream flood control. This operation is described in the February 1, 1996 PNCA data submittal.

4.2.3.10 John Day Project Operation

John Day was operated at elevation 80.0 m (262.5 ft) from mid-April through September as identified in the Salmon Biological Opinion. From October through mid-April, John Day operated to elevation 80.8 m (265 ft) [46.7 khm (191.0 ksfd)].

4.2.3.11 Corra Linn Project Operation

Kootenay Lake was operated as necessary, up to free flow, to maintain the lake level below the level specified by the IJC 1938 Order and the calculated "allowable elevation" at Queens Bay. This was implemented using the 5-step method as developed by the Columbia River Treaty Operating Committee. After August 31, the lake level was raised to elevation 532 m (1,745.3 ft) at the Queens Bay gage. This maximum elevation at Queens Bay was in effect through January 7. After January 7 the lake was lowered to elevation 531.6 m (1,744 ft) on February 1, elevation 531.1 m (1,742.4 ft) on March 1, and elevation 530.1 m (1,739.3 ft) on April 1. From April through August 31, if the lake exceeded elevation 530.1 m (1,739.3 ft) at the Queens Bay gage, then it was operated using the "allowable elevation" calculation to determine the Queens Bay maximum allowable elevation until the elevation at the Nelson gage drafted back to elevation 531.4 m (1,743.3 ft).

4.2.4 System Operations

4.2.4.1 McNary Flow Augmentation Objectives

During April 20 through June a sliding scale of flow augmentation objectives of 6,229.7 m^3/s (220,000 cfs) to 7,362.4 m^3/s (260,000 cfs) was used at McNary. It was based on The Dalles April 1, January through July volume runoff. A straight-line interpolation was used for flow objectives, for volume forecasts between 10,484.6 khm (85 MAF) and 12,951.6 khm (105.0 MAF). Maximum and minimum objectives are 7,362.4 m^3/s (260,000 cfs) and 6,229.7 m^3/s (220,000 cfs), when the volume forecast was greater than 12,951.6 khm (105.0 MAF) and less than 10,484.6 khm (85 MAF), respectively. The second half of April values were prorated with 4 days at 4,389.1 m^3/s (155,000 cfs) and 11 days at from 6,229.7 m^3/s (220,000 cfs) to 7,362.4 m^3/s (260,000 cfs). July and August flow objectives were 5,663.4 m^3/s (200,000 cfs). The priority for releasing water from upstream reservoirs for flow augmentation was Grand Coulee, Libby and Hungry Horse. The first priority was to support flow objectives and secondly to fill by June 30. These objectives are from the Salmon Biological Opinion.

Grand Coulee, Libby, and Hungry Horse operated in an attempt to meet these flow objectives down to the reservoir elevations or draft limits identified in the Al Wright E90 study. These draft limits were set at reservoirs to proportion augmentation between spring and summer season. Actual elevations of the draft limits are identified in the project operation paragraph for each reservoir.

4.2.4.2 Lower Granite Flow Augmentation Objectives

At Lower Granite a sliding scale was used to determine flow augmentation objectives. When the April 1, April through July runoff forecast at Lower Granite was less than 1,973.6 khm (16 MAF), then the mid-April through June 20 flow objective was 2,406.9 m^3/s (85,000 cfs) and the June 21 through August flow objective was 1,415.8 m^3/s (50,000 cfs). When the April 1, April through July forecast at Lower Granite was greater than 2,467.0 khm (20 MAF), then the mid-April through June 20 flow objective was 2,831.7 m^3/s (100,000 cfs). When the April 1, April through July forecast at Lower Granite was greater than 3,453.8 khm (28 MAF), then the June 21 through August flow objective was 1,557.4 m^3/s (55,000 cfs). The spring flow objectives were interpolated from forecasts between 1,973.6 khm (16 MAF) and 2,467.0 khm (20 MAF) and the spring flow objectives were interpolated for forecasts between 1,973.6 khm (16 MAF) and 3,453.8 khm (28 MAF). The first priority was to support flow objectives and secondly to fill by June 30. Dworshak utilized the

draft limits from the Al Wright E90 study discussed above. These objectives are from the Salmon Biological Opinion.

4.2.4.3 Vernita Bar Flow Augmentation Objective

The Vernita Bar minimum flow for December through May varied by water condition, with minimum flows established as the lesser of 68 percent of Wanapum's October or November flows, or 1,982.2 m^3/s (70,000 cfs). Values less than 1,982.2 m^3/s (70,000 cfs) are rounded to the nearest 1,41.6 m^3/s (5,000 cfs). The minimum protection level flow at Vernita Bar will be 1,415.8 m^3/s (50,000 cfs). These requirements are from the Vernita Bar Agreement and are in the 1997 PNCA Data Submittal.

4.2.4.4 Upper Snake Flow Augmentation

This operation tries to release 52.7 khm (427 KAF) from the upper Snake River in as many years as possible over the 60-year record during the May through August period. The adjustments to Brownlee inflows from the Upper Snake reservoir operations came from the BOR in May 1997. This requirement is identified in the Salmon Biological Opinion. See Table 4-6. BPA used 50 years of these data.

4.2.4.5 Operation Within 1 Percent Peak Efficiency

The Lower Snake River Hydropower Project (Lower Granite, Little Goose, Lower Monumental, and Ice Harbor) and the four lower Columbia River projects (McNary, John Day, The Dalles, and Bonneville) each were required to operate their turbines within 1 percent of peak efficiency during the period of March through November. This requirement is identified in the Salmon Biological Opinion. BPA modeled this requirement as reflected in a hydro availability file that limits the maximum generation capability of each project in each of the fourteen periods. No other hydropower outages were assumed.

4.2.4.6 Lower Snake Operation at Minimum Pool

The four lower Snake hydropower facilities were operated at Minimum Operating Pool (MOP) in accordance with the 1997 PNCA Data Submittal and the Salmon Biological Opinion. As identified in the Salmon Biological Opinion, Little Goose, Lower Monumental, and Ice Harbor were operated within one foot of MOP during the period from approximately April 10 through August 31. Lower Granite was operated within one foot of MOP from approximately April 10 through November 15. The MOP for Lower Granite, Little Goose, Lower Monumental, and Ice Harbor were elevations 223.4 m (733 ft), 192.9 m (633 ft), 163.7 m (537.7 ft), and 133.2 m (437 ft), respectively. During the rest of the year Lower Granite, Little Goose, Lower Monumental, and Ice Harbor were operated at elevations 224.9 m (738 ft), 194.5 m (638 ft), 164.6 m (540 ft), and 134.1 m (440 ft), respectively.

4.2.4.7 Juvenile Bypass Fish Spill at Federal Projects

Generation at the Lower Snake River Project and the four lower Columbia River projects (Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, John Day, The Dalles, and Bonneville) was reduced further with the inclusion of Juvenile Bypass Fish Spill as reflected in the Salmon Biological Opinion. When the regulated outflow at Lower Granite was less than 2,831.7 m^3/s (100,000 cfs), then there was no spill at the project; otherwise, spill was 80 percent of regulated flow at Lower Granite. If the regulated outflow at Lower Granite was less than

Table 4-6. Upper Snake 427 KAF Flow Augmentation—cfs

YEAR	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL
1928-29	(2289)	(693)	458	0	3624	0	0	0	0	0	(757)	(2440)
1929-30	(1810)	(1204)	223	1317	0	2559	364	0	0	0	(496)	(2089)
1930-31	(1764)	(1063)	270	0	1171	0	904	470	0	0	(732)	(2309)
1931-32	(2395)	(1220)	160	210	550	0	100	0	0	1446	1368	(2440)
1932-33	(1869)	623	878	107	148	0	169	256	264	697	1732	(2439)
1933-34	(1848)	423	960	135	100	200	432	0	0	42	(460)	(2029)
1934-35	(306)	(536)	484	78	42	33	8	(3)	0	0	(248)	(2439)
1935-36	(1628)	(249)	324	78	234	202	11	(8)	1466	1831	(534)	(2440)
1936-37	(2440)	(802)	56	164	48	0	541	616	331	0	(697)	(2213)
1937-38	(1274)	(412)	797	200	182	200	1194	2329	3693	3232	(521)	(2440)
1938-39	(2099)	(1030)	1724	380	1275	2213	0	0	1078	0	(756)	(2413)
1939-40	(2175)	(1228)	120	11	0	0	7	386	2440	936	(699)	(2440)
1940-41	(2339)	(522)	1095	594	759	0	571	298	368	391	217	(2080)
1941-42	(2440)	(933)	1447	857	940	0	93	477	1805	950	(642)	(2440)
1942-43	(2440)	(659)	641	0	693	360	866	5879	5	26	633	(2439)
1943-44	(2416)	(1378)	560	648	855	0	200	738	1	0	(621)	(2356)
1944-45	(2000)	(1304)	305	487	1370	2916	1357	0	1261	258	550	(2440)
1945-46	(2440)	(46)	650	737	2696	91	603	130	892	0	(757)	(2440)
1946-47	(2100)	(1078)	639	1	4374	558	640	68	0	0	(757)	(2440)
1947-48	(2100)	(987)	1512	0	3038	0	0	169	818	621	(756)	(2440)
1948-49	(2100)	(963)	1654	96	122	2469	0	816	743	0	(604)	(2440)
1949-50	(2100)	(578)	1348	384	0	2217	0	568	958	0	0	(2439)
1950-51	(2439)	(1078)	2127	2808	545	171	336	0	0	0	(756)	(2440)
1951-52	(2434)	(826)	500	1932	515	3075	12	0	0	0	(756)	(2440)
1952-53	(2440)	(1054)	1667	150	2788	410	715	0	853	0	0	(2439)
1953-54	(2099)	(1078)	785	2161	0	1013	715	306	688	0	(756)	(2439)
1954-55	(2440)	(839)	538	2910	0	1478	100	0	0	292	(191)	(2240)
1955-56	(2339)	(656)	665	570	1291	3740	0	163	0	13	(756)	(2440)
1956-57	(2439)	154	522	911	2430	0	738	116	798	0	(251)	(2440)
1957-58	(2289)	(609)	544	33	3794	0	481	120	600	0	(756)	(2440)
1958-59	(2290)	(733)	707	313	0	2846	983	561	805	0	(757)	(2440)
1959-60	(2321)	(1079)	150	197	298	2137	1068	657	1	902	(756)	(2439)
1960-61	(2019)	313	362	64	392	0	882	195	0	321	(130)	(2440)
1961-62	(2439)	(1043)	1022	845	99	0	1874	1085	3563	992	(756)	(2440)
1962-63	(1949)	(578)	1104	2175	899	691	26	0	671	(1	(757)	(2440)
1963-64	(2290)	(754)	465	990	1116	2072	694	236	91	406	0	(2440)
1964-65	(2440)	(1013)	1705	0	3518	400	0	185	50	0	0	(2439)
1965-66	(1839)	578	1628	989	264	0	0	0	0	430	(342)	(2440)
1966-67	(2439)	(1304)	147	16	0	0	133	786	4058	1840	0	(2440)
1967-68	(2440)	105	616	0	2495	252	0	0	55	407	259	(2439)
1968-69	(2339)	(608)	536	0	1369	1917	1659	348	107	114	(756)	(2440)
1969-70	(2146)	(578)	1534	109	932	2038	507	1	694	0	(242)	(2440)
1970-71	(2440)	(1078)	850	329	2085	2844	0	0	0	0	(757)	(1714)
1971-72	(987)	125	1434	489	174	254	516	460	0	0	0	(2439)
1972-73	(2440)	(1078)	3713	617	240	0	448	0	0	0	(700)	(2439)
1973-74	(1493)	(845)	472	2580	1844	1031	440	0	0	0	(756)	(2439)
1974-75	(2282)	(1378)	2660	2364	217	0	353	121	1157	0	0	(2440)
1975-76	(987)	(1378)	2373	314	2005	43	0	0	0	0	0	(2439)
1976-77	(2440)	(1378)	548	3283	100	0	238	419	252	0	(756)	(2440)
1977-78	(2440)	(804)	0	205	260	0	0	363	3696	2346	1329)	(2336)
1978-79	(2439)	(1378)	924	20	1935	830	207	758	546	0	(399)	(2366)
1979-80	(2340)	(1024)	237	9	2100	1033	1210	756	995	1209	(458)	(2440)
1980-81	(2439)	(1164)	1601	0	2343	1432	0	100	467	186	(757)	(2439)
1981-82	(2440)	(662)	517	251	1596	1407	1194	1352	(3)	0	0	(2439)
1982-83	(1697)	(356)	1990	850	1048	504	0	88	0	0	(756)	(1712)
1983-84	(785)	(1378)	2421	957	1112	59	7	0	0	0	(756)	(2055)
1984-85	(648)	(1378)	2438	502	649	150	173	174	485	217	(756)	(2439)
1985-86	(2339)	(1033)	1426	1292	625	1368	604	1190	0	0	(757)	(2439)
1986-87	(2289)	(1003)	3252	1561	34	0	0	0	0	100	(656)	(2439)
1987-88	(2440)	(1378)	0	23	37	0	70	0	0	0	(756)	(2059)
1988-89	(2440)	(1364)	962	790	60	200	0	0	5984	1288	(376)	(1969)

Note: Minus numbers are in parentheses and are a release from storage.

2,406.9 m^3/s (85,000 cfs), then there was no spill at Little Goose and Lower Monumental; otherwise, spill was 80 and 81 percent of regulated flow at Little Goose and Lower Monumental, respectively. Bonneville had a daytime spill cap of 2,123.8 m^3/s (75,000 cfs) from 0600 to 1800 hours. Juvenile Bypass Fish Spill at Federal projects (in percent of regulated flow), limited by Spill Caps, is shown in Table 4-7. The spill caps represent completed modifications at spillways currently planned and which are used as hydroregulation modeling caps, not instantaneous.

Table 4-7. Juvenile Bypass Fish Spill (Percent of Regulated Flow) and Spill Cap (cfs)-Federal Projects

	MAR	APR 1	APR 2	MAY	JUN	JUL	AUG1	AUG 2	CAP (cfs)	CAP (m^3/s)
Bonneville	23.0		49.9	68.0	68.0	77.0	77.0	77.0	100,000	2,831.7
The Dalles			46.9	64.0	64.0	64.0	64.0	64.0	230,000	6,512.9
John Day			12.1	16.5	16.5	43.0	43.0	43.0	60,000	1,699
Ice Harbor		10.8	27.0	27.0	41.3	70.0	70.0	70.0	60,000	1,699
McNary			18.3	25.0	25.0				60,000	1,699
Lower Monumental		16.2	40.5	40.5	27.0				20,000	566.3
Little Goose		16.0	40.0	40.0	26.7				25,000	707.9
Lower Granite		16.0	40.0	40.0	26.7				22,500	637.1

BPA used spill caps as submitted by the Corps in OY97 PNCA planning which differed from this table at The Dalles [5,380.2 m^3/s (190,000 cfs)], John Day [1,699.0 m^3/s (6,000 cfs)], and McNary [1,982.2 m^3/s (70,000 cfs)].]

4.2.4.8 Juvenile Bypass Fish Spill at Non-Federal Projects

Generation was also reduced for juvenile bypass spill at non-Federal projects. The percent of regulated flow and spill caps is described in Table 4-8 and was submitted for operating year 1996-97 PNCA planning. Rock Island spill is described in cfs.

4.2.5 BPA Operational Step

4.2.5.1 Loads and Secondary Market

BPA used PNCA firm Loads based on operating year 1998 projections made by the Marketing Analysis, Bulk Power Marketing Branch, were used in the Operational Step. A 9,000 aMW secondary load limit was used in every period of every year.

4.2.5.2 Variable Energy Content Curve

BPA used VECCs that were calculated using OY97 PDRs. Although VECC lower limits were eliminated from OY97 refill studies, a lower limit of 379.5 m (1,245 ft) in January, 371.9 m (1,220 ft) for February through April, 378 m (1,240 ft) in May, and 391.7 m (1,285 ft) in June at Grand Coulee was used in calculating the VECC during period in which the system is generating surplus energy. The Canadian AOP VECCs were based on historical volumes. The VECCs for the Federal projects were based on the Kuehl Moffitt volume forecasts.

Table 4-8. Juvenile Bypass Fish Spill (Percent of Regulated Flow) and Spill Cap (cfs)-Non-Federal Projects

PROJECTS:	APR1	APR 2	MAY	JUN	JUL	AUG1	CAP (cfs)	CAP (m^3/s)
Wells	0.0	6.5	6.5	0.0	6.5	2.5	10,000	283.2
Rocky Reach	0.0	12.0	15.0	4.0	8.0	4.0	5,000	141.6
Wanapum	0.0	10.0	25.0	2.5	14.2	20.0	10,000	283.2
Priest Rapids	0.0	7.0	35.0	5.8	13.5	20.0	25,000	707.9

Rock Island	PERIOD AVERAGE SPILL (cfs)	PERIOD AVERAGE SPILL (m^3/s)
April 1-15	4,800	135.9
April 16-30	19,300	546.5
May	23,000	651.3
June	23,000	651.3
July	23,000	651.3
August 1-15	19,300	546.5
August 16-31	4,800	135.9

4.2.5.3 Libby Project Operation

BPA operated Libby in the same manner as in the AER step with the following exceptions. Libby was operated mid-April through July for protection of sturgeon in all but 20 percent of the driest years (see Table 4-9, Libby Sturgeon Flow Objective, for years which no releases are provided) by meeting Bonners Ferry minimum flows. Sturgeon Flow Objectives included May 1 through May 9, minimum flow at Bonners Ferry is 424.8 m^3/s (15,000 cfs); May 10 through June 20, Libby outflow reflects a full turbine operation; June 21 through July 11, minimum flow at Bonners Ferry is 311.5 m^3/s (11,000 cfs). The following table (Table 4-9) shows the computed Libby outflow required in the years when sturgeon releases were provided (assuming project discharge during a full turbine operation was equal to 707.9 m^3/s (25,000 cfs). If the reservoir was above 743.4 m (2,439 ft), the project discharged up to powerhouse capacity, without spill, to support the McNary flow augmentation objectives.

4.2.5.4 Grand Coulee Project Operation

BPA operated Grand Coulee's during the September through December period the same as in the AER step. Grand Coulee was operated for power but no lower than the Biological Rule Curves as implemented in the AER January through mid-April. Grand Coulee was operated as low as 381 m (1,250.0 ft) [283.5 khm (1,159.1 ksfd)] in the second half of April and as low as 390.1 m (1,280.0 ft) or flood control [542.1 khm (2,216.4 ksfd)] in May through August to try to meet the McNary flow augmentation objectives. At-site minimum flow was 1,415.8 m^3/s (50,000 cfs) for peaking purposes.

4.2.5.5 Juvenile Bypass Fish Spill at Federal Projects

Juvenile bypass fish spill at Federal projects were the same as the AER Step, except the cap was adjusted as shown below in Table 4-10.

Table 4-9. Libby Sturgeon Flow Objectives

	May	June	July
1929	No	No	No
1930	No	No	No
1931	No	No	No
1932	18903	18000	5312
1933	18903	18000	4245
1934	18903	18436	5760
1935	18903	18000	5315
1936	No	No	No
1937	18903	18000	5592
1938	18903	18000	5283
1939	No	No	No
1940	19660	19124	6165
1941	No	No	No
1942	19094	18000	4784
1943	18903	18000	4596
1944	No	No	No
1945	18903	18108	5803
1946	18903	18000	5244
1947	18903	18000	5676
1948	18903	18000	5052
1949	18903	18413	5951
1950	18903	18000	4117
1951	18903	18000	5311
1952	18903	18000	5126
1953	18903	18000	5449

	May	June	July
1954	18903	18000	4000
1955	18903	18000	4810
1956	18903	18000	5101
1957	18903	18256	5770
1958	18903	19133	5985
1959	18903	18000	5038
1960	18903	18000	5504
1961	18903	18000	5590
1962	18903	18000	5723
1963	19023	18000	5529
1964	18903	18000	5345
1965	18903	18000	5435
1966	18903	18000	5379
1967	18903	18000	5489
1968	18903	18000	5465
1969	18903	18000	4890
1970	No	No	No
1971	18903	18000	4448
1972	18903	18000	5484
1973	20018	19407	6268
1974	18903	18000	4431
1975	18903	18000	5464
1976	18903	18240	5201
1977	No	No	No
1978	18903	18324	5465

Table 4-10. Federal Project Spill Caps

Project	CAP (m^3/s)	CAP (cfs)
Bonneville	2,831.7	100,000
The Dalles	6,512.9	230,000
John Day	1,699.0	60,000
Ice Harbor	1,699.0	60,000
McNary	1,699.0	60,000
Lower Monumental	566.3	20,000
Little Goose	707.9	25,000
Lower Granite	637.1	22,500

4.3 Alternative A2

Alternative A2 is a continuous study of the system operations under a scenario where the Base Condition (Alternative A1) spill was adjusted without drawdown of the Lower Snake River or John Day reservoirs. The alternative relies on fish transportation as the primary method for fish passage and assumes the current level of development of fish facilities. This alternative eliminates fish spill at Lower Granite, Little Goose, Lower Monumental and McNary, the fish transportation projects.

4.3.1 System Demand

The loads and secondary market limit used in this alternative were the same as Alternative A1, see Section 4.2.1.

4.3.2 Rule Curves

The flood control rule curves, Variable Energy Content Curves and Critical Rule Curves used in this alternative were the same as Alternative A1, see Section 4.2.2.

4.3.3 Project Operations

Reservoirs were initialized to the same storage content used in Alternative A1. Projects operated to the same non-power requirements used in Alternative A1. Other project operations used in this alternative remained unchanged from Alternative A1, see Section 4.2.3.

4.3.4 System Operations

The McNary, Lower Granite, and Vernita Bar flow augmentation objectives used in this alternative were the same as Alternative A1. Upper Snake flow augmentation used in this alternative was the same as Alternative A1. The four Lower Columbia projects and the Lower Snake River Project continued to operate within 1 percent of peak efficiency. The minimum pool operation at the Lower Snake River Project remained unchanged. Spill for juvenile bypassing remained the same as Alternative A1 at non-Federal projects, but changed at the Federal projects. Spill at collector facilities such as Lower Granite, Little Goose, Lower Monumental, and McNary is removed. For the spill requirements at Bonneville, The Dalles, John Day, and Ice Harbor, see Section 4.2.4. A description of other system operations are found in Section 4.2.4.

4.3.5 BPA Operational Step

The loads, secondary market and Variable Energy Content Curves used in this alternative were the same as Alternative A1. The Libby and Grand Coulee project operations used in this alternative were the same as Alternative A1. Spill at collector projects such as Lower Granite, Little Goose, Lower Monumental, and McNary was removed. For the spill requirements at Bonneville, The Dalles, John Day, and Ice Harbor, see Section 4.2.5.5. Other requirements for the BPA Operational Step are described in Section 4.2.5.

4.4 Alternative A3

Alternative A3 is a continuous study of the system operations under a scenario where the Base Condition (Alternative A1) was adjusted only for drawdown of Lower Granite, Little Goose, Lower Monumental, and Ice Harbor, to natural river levels. Flow augmentation requirements on the Snake and Columbia rivers were not changed. It was assumed that non-Federal owners would remove their

reservoirs from planning, thereby not requiring them to draft to meet load. Non-Federal projects were fixed on the operation resulting from the Base Condition regulation. Federal projects were allowed to pick up as much of the load lost from removing the lower Snake plants while still meeting project non-power requirements.

4.4.1 System Demand

The loads and secondary market limit used in this alternative were the same as Alternative A1, see Section 4.2.1.

4.4.2 Rule Curves

The flood control rule curves, Variable Energy Content Curves and Critical Rule Curves used in this alternative were the same as Alternative A1, see Section 4.2.2.

4.4.3 Project Operations

Reservoirs were initialized to the same storage content used in Alternative A1. Projects operated to the same non-power requirements used in Alternative A1. Other project operations used in this alternative remained unchanged from Alternative A1, except at the Lower Snake River Project which was drawn down to natural river. For a description of project operations see Section 4.2.3.

4.4.4 System Operations

The McNary, Lower Granite, and Vernita Bar flow augmentation objectives used in this alternative were the same as Alternative A1. Upper Snake flow augmentation used in this alternative was the same as Alternative A1. The Lower Snake River Project was drawn down to natural river, therefore, generation at these plants was eliminated and efficiency requirements no longer apply. The Lower Snake River Project MOP operation was removed. In addition, fish spill at these plants no longer applies. Spill at other Federal and Non-Federal plants remains unchanged. For a description of project operations see Section 4.2.4. For a description of project operations see Section 4.2.4. BPA reflected this requirement in the hydropower availability file which limited the maximum generation capability of the Lower Snake River Project in each of the 14 periods to zero.

4.4.5 BPA Operational Step

The loads, secondary market and Variable Energy Content Curves used in this alternative were the same as Alternative A1. The Libby and Grand Coulee project operations used in this alternative were the same as Alternative A1. The Lower Snake River Project was drawn down to natural river levels, therefore spill for fish, operation within 1 percent of peak efficiency, and the MOP operation no longer apply. Other requirements for the BPA Operational Step are described in Section 4.2.5.

4.5 Alternative A5

Alternative A5 is a continuous study of the system operations under a scenario where the Base Condition (Alternative A1) was adjusted for the drawdown of the Lower Snake River Project to natural river level and to remove flow augmentation at Lower Granite. The upper Snake River flow augmentation was removed. It was assumed that non-Federal owners would remove their reservoirs from planning, thereby not requiring them to draft to meet load. Non-Federal projects were fixed on the operation resulting from the Base Condition regulation. Federal projects were allowed to pick

up as much of the load lost from removing the Lower Snake plants while still meeting project non-power requirements. Dworshak operation was allowed to meet FELCC September through May, observing a summer recreation requirement to be above elevation 486.2 m (1,595 ft).

4.5.1 System Demand

The loads and secondary market limit used in this alternative were the same as Alternative A1, see Section 4.2.1.

4.5.2 Rule Curves

Dworshak and Brownlee projects provide both system and local flood control space in their reservoirs during the flood control evacuation period. To allow these projects to store more water for flow augmentation purposes, the system flood control requirement at these two projects were shifted to Grand Coulee project. This was done when the April-July volume forecasts are less than 394.7 khm (3.2 MAF) and 715.4 khm (5.8 MAF), respectively. The flood control used in this alternative was the same as Alternative A1 (see Section 4.2.2), except the system flood control was not shifted to Grand Coulee because the Snake River flow augmentation requirement was removed.

The Variable Energy Content Curves and Critical Rule Curves used in this alternative were the same as Alternative A1, see Section 4.2.2.

4.5.3 Project Operations

Reservoirs were initialized to the same storage content used in Alternative A1, with the exception of Dworshak that was initialized to elevation 487.7 m (1,600 ft). Projects were operated to the same non-power requirements used in Alternative A1. Other project operations used in this alternative remained unchanged from Alternative A1, except at Dworshak and Brownlee.

Dworshak was allowed to meet FELCC September 1 through May 31. Dworshak was limited to a discharge of 707.9 m^3/s (25,000 cfs) for flood control. For recreation during June through August, the reservoir was held to above elevation 486.2 m (1,595 ft). In October, the maximum discharge is equal to inflow plus 36.8 m^3/s (1,300 cfs). There are no draft limits or 85 percent confidence of reaching flood control on April 20.

Brownlee was operated to meet FELCC. The operation had flood control, 566.3 m^3/s (20,000 cfs) maximum flow in October and 254.9 m^3/s (9,000 cfs) maximum flow in November imposed over the fixed operation used in PNCA planning.

4.5.4 System Operations

The McNary and Vernita Bar flow augmentation objectives used in this alternative were the same as Alternative A1. The Lower Granite flow augmentation objectives was removed. The Upper Snake reservoir operations was adjusted to release 52.7 khm (427 KAF). The Lower Snake River Project was drawn down to natural river, therefore, generation at these plants were eliminated and efficiency requirements no longer apply. The Lower Snake River Project MOP operation was removed and fish spill at these plants no longer applies. Spill at other Federal and Non-Federal plants remained unchanged.

4.5.5 BPA Operational Step

The loads and secondary market used in this alternative were the same as Alternative A1.

Although VECC lower limits were eliminated from OY97 refill studies, a lower limit of 379.5 m (1,245 ft) in January, 371.9 m (1,220 ft) in February through April, 378.0 m (1,240 ft) in May, and 391.7 m (1,285 ft) in June at Coulee was used in calculating the VECC during periods in which the system was generating surplus energy. The Canadian AOP VECCs were based on historical volumes and the Arrow Total method. The VECCs for the Federal projects were based on the Kuehl Moffitt volume forecasts.

Libby was operated in the same manner as in the AER studies with the following exceptions. Libby was operated mid-April through July for protection of sturgeon in all but 20 percent of the driest years (see Flow Objective Table 4-9 for years when no releases were provided) by meeting Bonners Ferry minimum flows. Sturgeon objectives included May 1 through 9, minimum flow at Bonners Ferry was 424.8 m^3/s (15,000 cfs); May 10 through June 20, Libby outflow reflected a full turbine operation; June 21 through July 11, minimum flow at Bonners Ferry was 311.5 m^3/s (11,000 cfs). The table shows the computed Libby outflow required in the years when sturgeon releases were provided (assuming project discharge during a full turbine operation is equal to 707.9 m^3/s [25,000 cfs]). If the reservoir was above 743.4 m (2,439 ft), the project discharged up to powerhouse capacity, without spill, to support the McNary flow augmentation objective.

Grand Coulee's operation during the September through December period was the same as in the AER step. Grand Coulee was operated for power but no lower than the Biological Rule Curves as implemented in the AER January through mid-April. Grand Coulee was operated as low as 381.0 m (1,250.0 ft) [283.5 khm (1,159.1 ksfd)] in the second half of April and as low as 390.1 m (1,280.0 ft) or flood control [542.1 khm (2,216.4 ksfd)] in May through August to try to meet the McNary flow augmentation objective. At-site minimum flow was 1,415.8 m^3/s (50,000 cfs) for peaking purposes.

4.6 Alternative A6a

Alternative A6a is a continuous study of the system operations augmentation of an additional 176 khm (1 MAF) (1,427 KAF total) over the Base Condition (Alternative A1) from the upper Snake River. Priority to refill by June 30 for biological purposes was provided by reducing the flow augmentation objectives in low water years on the Snake River at Lower Granite.

4.6.1 System Demand

The loads and secondary market limit used in this alternative were the same as Alternative A1 (see Section 4.2.1).

4.6.2 Rule Curves

The flood control rule curves, Variable Energy Content Curves and Critical Rule Curves used in this alternative were the same as Alternative A1 (see Section 4.2.2).

4.6.3 Project Operations

Reservoirs were initialized to the same storage content used in Alternative A1. Projects were operated to the same non-power requirements used in Alternative A1. Other project operations used in this alternative remained unchanged from Alternative A1 (see Section 4.2.3).

4.6.4 System Operations

The McNary and Vernita Bar flow augmentation objectives used in this alternative were the same as Alternative A1. Lower Granite sliding scale flow augmentation objectives were lowered during low flow years to assist reservoir refill by June 30. For spring flow objective (10 April to 20 June), when the April 1, April through July runoff forecast is less than 1,233.5 khm (10 MAF), the project was operated on minimum flow or URC except in May where the Lower Granite objective was 1,699 m^3/s (60,000 cfs). For spring flows when the forecast is 1,233.5 khm (10 MAF) to 1,973.6 khm (16 MAF), April and June operation was on minimum flow or URC. The May flow objective ranged, on a sliding scale, from 1,699 m^3/s (60,000 cfs) to 2,406.9 m^3/s (85,000 cfs). For spring flows when the forecast was 1,973.6 khm (16 MAF) to 2,467.0 khm (20 MAF), flow objective ranged, on a sliding scale, from 2,406.9 m^3/s (85,000 cfs) to 2,831.7 m^3/s (100,000 cfs). When forecast was greater than 2,467.0 khm (20 MAF), then the mid-April through June 20 flow objective was 2,831.7 m^3/s (100,000 cfs). For summer flow objective (21 June through August), when the forecast was less than 1,973.6 khm (16 MAF), the flow objective was 1,415.8 khm (50,000 cfs). For summer, when the forecast was 1,973.6 khm (16 MAF) to 3,453.8 khm (28 MAF), flow objectives ranged from 1,415.8 khm (50,000 cfs) to 1,557.4 m^3/s (55,000 cfs). For summer when the forecast was greater than 3,453.8 khm (28 MAF), flow objective was 1,557.4 m^3/s (55,000 cfs).

Upper Snake flow augmentation used in this alternative was increased to 176.0 khm (1,427 KAF), 123.3 khm (1 MAF) over the Base Condition. The Upper Snake reservoir operations adjustments to Brownlee inflows came from the BOR in June 1998. The operation tries to release 176.0 khm (1,427 KAF) in as many years as possible over the 60-year record during the May through August period. Adjustments were made based on the "Reservoir Emphasis" alternative. The reservoir emphasis alternative utilized irrigation, thereby protecting Upper Snake River reservoirs. BPA used 50 years of these data. See Table 4-11.

The four Lower Columbia projects and the Lower Snake River Project continued to operate within 1 percent of peak efficiency. The minimum pool operation at the Lower Snake River Project remained unchanged. Spill for juvenile bypassing remained the same as Alternative A1 at non-Federal projects and at the Federal projects.

A description of other system operations that were unchanged is found in Section 4.2.4.

4.6.5 BPA Operational Step

The Operational Step was run by BPA. All project operations were modeled as in the AER step except as specifically addressed below. PNCA firm Loads based on OY98 projections by the Marketing Analysis, Bulk Power Marketing Branch were used in this study. A limited secondary market of 9,000 a MW was used in every period, every year.

VECCs were calculated using OY97 PDRs. Although VECC lower limits were eliminated from OY97 refill studies, a lower limit of 379.5 m (1,245 ft) in January, 371.9 m (1,220 ft) February through April, 378.0 m (1,240 ft) in May, and 391.7 m (1,285 ft) in June at Coulee was used in calculating the VECC during period in which the system was generating surplus energy. The Canadian AOP VECCs were based on historical volumes and the Arrow Total method. The VECCs for the Federal projects were based on the Kuehl Moffitt volume forecasts.

Table 4-11. Upper Snake River Flow Augmentation (cfs)

	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	AP2	MAY	JUN	JUL
1929	(13803)	467	292	1634	311	246	220	644	315	(331)	1174	(251)
1930	342	858	515	373	1846	283	(221)	320	310	(11563)	(9117)	(97)
1931	484	226	224	296	293	227	220	198	700	(11452)	(9391)	120
1932	(17567)	1365	803	511	369	366	312	(44	(464)	145	(916)	(388)
1933	(10005)	1132	439	389	352	285	69	346	4525	(3431)	184	(438)
1934	259	674	492	300	319	118	152	413	534	(22488)	(465)	(315)
1935	(381)	1178	695	365	398	52	298	201	(773)	(8758)	(3667)	(3333)
1936	(837)	958	574	623	354	392	184	(1086)	579	(1659)	(11804)	(6148)
1937	151	457	558	421	352	1059	225	1247	641	270	(15437)	(5548)
1938	(17801)	101	806	409	526	1995	772	5331	(2355)	1806	(1925)	(411)
1939	28	79	353	6013	2585	304	185	(539	1419	556	(22309)	(226)
1940	25	758	661	453	336	285	614	1575	2265	1990	(13957)	(7368)
1941	12	417	248	349	356	173	302	272	1624	(5010)	(6415)	(6914)
1942	(17111)	539	176	745	1687	1820	231	1063	7374	1167	(2525)	(313)
1943	(9045)	462	70	374	(718)	6439	(1202)	2195	(2717)	218	(85)	(317)
1944	35	212	3522	437	318	316	310	311	299	(8696)	(7906)	(1434)
1945	(17650)	507	183	372	4221	325	327	295	846	2515	176	(106)
1946	(16363)	566	7500	1266	321	182	1554	2450	(3055)	(421)	(1927)	(136)
1947	(17566)	568	308	4224	1045	389	333	3902	1088	(1141)	(938)	(733)
1948	(8560)	877	120	6084	958	523	329	117	764	93	(134)	(468)
1949	(9764)	221	(1492)	673	504	111	332	(160)	583	449	(5437)	(3313)
1950	(8713)	739	1343	401	533	927	(46)	2303	1656	1065	(1242)	(112)
1951	(15946)	2600	1322	638	665	108	1176	1025	(3061)	79	(81)	(516)
1952	(17343)	48	6891	1891	896	788	339	3193	897	110	(1034)	(523)
1953	(8704)	270	107	3856	1329	330	134	1848	311	1086	(880)	(353)
1954	(10212)	349	1228	426	418	303	(386)	966	310	(800)	(387)	(731)
1955	(8892)	783	222	2534	1189	298	310	315	1318	1844	(595)	(323)
1956	(17604)	67	168	434	(1475)	1188	(2353)	198	(1033)	(94)	(1120)	(582)
1957	(17508)	215	4219	3678	336	210	704	3207	334	(161)	(447)	(1049)
1958	(17306)	633	2906	5266	213	331	1891	1151	(3049)	1138	(231)	(706)
1959	(12739)	1163	305	563	3425	919	165	(627)	5558	(4240)	(1605)	(642)
1960	(8528)	821	205	1064	1038	332	310	345	302	(7490)	(995)	(466)
1961	(4033)	557	530	458	358	246	360	43	268	(5148)	(1085)	(6607)
1962	(7067)	487	231	405	357	(99	(883)	539	244	(3816)	(897)	(322)
1963	(14494)	285	894	2725	2778	151	332	(411)	795	159	117	(308)
1964	(7862)	465	122	507	2747	335	328	(825)	1596	201	179	(491)
1965	(2518)	559	828	638	(811)	1081	(380	1038	(1030)	(194)	(1722)	(356)
1966	(9)	678	(125)	317	305	302	324	291	504	(13874)	(6947)	(385)
1967	(13713)	153	140	412	359	1373	1549	1361	4061	(2268)	398	(653)
1968	(8527)	352	5891	853	465	313	326	279	882	(5731)	(1491)	(305)
1969	(17239)	3231	3878	352	409	717	(69)	817	(2216)	736	(1212)	(646)
1970	(9572)	826	1476	4267	449	713	(302	1028	236	2850	(1550)	(607)
1971	(6631)	2487	459	1013	481	2032	(376	1042	(1032)	358	(1998)	(608)
1972	(9773)	4699	410	373	367	142	1675	621	1574	(1509)	(186)	(645)
1973	(411)	5360	597	355	295	299	328	51	275	(1147)	(17178)	(240)
1974	(5800)	437	7438	630	948	2394	136	2296	(1032)	1562	(2381)	(787)
1975	(4114)	2151	748	400	320	(417)	334	592	(549)	1892	(116)	(729)
1976	(5022)	2460	600	345	302	257	(195)	123	301	289	(215)	(396)
1977	536	2367	915	406	204	299	311	313	(2802)	(18798)	635)	482)
1978	(9183)	786	668	507	357	266	(579)	(3167)	(855)	43	42	(243)
1979	(7192)	731	3931	717	435	320	332	54	425	674	(1217)	(8272)
1980	(12396)	648	209	517	2438	95	334	3820	(2491)	1085	(1100)	(1250)
1981	(16408)	1053	61	3528	1310	609	610	368	672	1733	(1879)	(1413)
1982	(7301)	1047	189	871	1074	1550	1008	996	(1018)	174	(1193)	(747)
1983	(3677)	4699	850	(22)	296	1348	1304	183	(108)	(173)	(349)	(234)
1984	(3362)	2724	(271)	400	779	632	1610	617	896	(259)	(1982)	(470)
1985	(623)	1620	341	681	28	312	2	791	280	1752	(6997)	(10875)
1986	(13303)	1491	(52)	3306	1470	(1620)	1630	622	5108	(2652)	(186)	(2340)
1987	158	5933	2033	419	318	312	329	295	323	(9240)	(11017)	659)
1988	380	573	622	449	364	312	289	2100	295	(4062)	(16699)	(102)
1989	(5342)	870	538	440	367	152	306	(2652)	97	(837)	(6193)	(3590)

Notes: Minus numbers are in parentheses and are a release from storage.
1,427 KAF Reservoir Emphasis Data

H:\WP\1346\Appendices\FEIS\G - Hydroregulations\CamRdy\App_G.doc

Libby was operated in the same manner as in the AER studies with the following exceptions. Libby was operated mid-April through July for protection of sturgeon in all but 20 percent of the driest years (see Flow Objective Table 4-9 for years when no releases were provided) by meeting Bonners Ferry minimum flows. Sturgeon objectives included May 1 through May 9, minimum flow at Bonners Ferry was 424.8 m^3/s (15,000 cfs); May 10 through June 20, Libby outflow reflected a full turbine operation; June 21 through July 11, minimum flow at Bonners Ferry was 311.5 m^3/s (11,000 cfs). The table shows the computed Libby outflow required in the years when sturgeon releases were provided (assuming project discharge during a full turbine operation was equal to 707.9 m^3/s [25,000 cfs]). If the reservoir was above 743.4 m (2,439 ft), the project discharged up to powerhouse capacity, without spill, to support the McNary flow augmentation objective.

Grand Coulee's operation during the September through December period was the same as in the AER step. Grand Coulee was operated for power but no lower than the Biological Rule Curves as implemented in the AER January through mid-April. Grand Coulee was operated as low as 381.0 m (1,250.0 ft) [283.5 khm (1,159.1 ksfd)] in the second half of April and as low as 390.1 m (1,280.0 ft) or flood control [542.1 khm (2,216.4 ksfd)] in May through August to try to meet the McNary flow augmentation objective. At-site minimum flow was 1,415.8 m^3/s (50,000 cfs) for peaking purposes.

Juvenile bypass fish spill at Federal projects was the same as the AER Step, except that the cap was adjusted as shown below.

	CAP (cfs)	CAP (m^3/s)
BON 320	100,000	2,831.7
TDA 365	230,000	651.3
JDA 440	60,000	1,699.0
IHR 502	60,000	1,699.0
MCN 488	60,000	1,699.0
LMN 504	20,000	566.3
LGS 518	25,000	707.9
LWG 520	22,500	637.1

4.7 Alternative A6b

Alternative A6b is a continuous study of the system operations under the Base Condition (Alternative A1) with no flow augmentation from the upper Snake River. The 52.7 khm (427 KAF) (52.7 khm) upper Snake River flow augmentation used in A1 was removed. Columbia River and Snake River flow augmentation objectives were retained. Priority to refill by June 30 for biological purposes was provided by reducing the flow augmentation objectives in low water years on the Snake River at Lower Granite.

4.7.1 System Demand

The loads and secondary market limit used in this alternative were the same as Alternative A1 (see Section 4.2.1).

4.7.2 Rule Curves

The flood control rule curves, Variable Energy Content Curves, and Critical Rule Curves used in this alternative were the same as Alternative A1 (see Section 4.2.2).

4.7.3 Project Operations

Reservoirs were initialized to the same storage content used in Alternative A1. Projects were operated to the same non-power requirements used in Alternative A1. Other project operations used in this alternative remained unchanged from Alternative A1 (see Section 4.2.3).

4.7.4 System Operations

The McNary and Vernita Bar flow augmentation objectives used in this alternative were the same as Alternative A1. The Lower Granite sliding scale flow augmentation objective was lowered during low flow years to assist reservoir refill by June 30. For spring flow objectives (April 10 to June 20), when the April 1, April through July runoff forecast was less than 1,233.5 khm (10 MAF), the project was operated and on minimum flow or URC except in May where the Lower Granite objective was 1,699.0 m^3/s (60,000 cfs). For spring flows when the forecast is 1,233.5 khm (10 MAF) to 1,973.6 khm (16 MAF), April and June operation will be on minimum flow or URC. The May flow objective ranged, on a sliding scale, from 1,699.0 m^3/s (60,000) to 2,406.9 m^3/s (85,000 cfs). For spring flows when the forecast was 1,973.6 m^3/s (16 MAF) to 2,467.0 khm (20 MAF), flow objectives ranged, on a sliding scale, from 2,406.9 m^3/s (85,000) to 2,831.7 m^3/s (100,000 cfs). When the forecast was greater than 2,467.0 khm (20 MAF), the mid-April through June 20 flow objective was 2,831.7 m^3/s (100,000 cfs). For summer flow objectives (June 21 through August), when the forecast was less than 1,973.6 m^3/s (16 MAF), the flow objective was 1,415.8 m^3/s (50,000 cfs). For summer, when the forecast was 1,973.6 m^3/s (16 MAF) to 3,453.8 khm (28 MAF), flow objective ranged from 1,415.8 m^3/s (50,000) to 1,557.4 m^3/s (55,000 cfs). For summer when the forecast was greater than 3,453.8 khm (28 MAF), flow objective was 1,557.4 m^3/s (55,000 cfs).

Upper Snake flow augmentation used in this alternative was decreased to zero. BPA used 50 years of these data.

The four lower Columbia River projects and the Lower Snake River Project continued to operate within 1 percent of peak efficiency. The minimum pool operation at the Lower Snake River Project remained unchanged. Spill for juvenile bypassing remained the same as Alternative A1 at non-Federal projects and at the Federal projects. A description of other system operations that were unchanged is found in Section 4.2.4.

4.7.5 BPA Operational Step

The operational step was performed the same as Alternative A6a, as shown in Section 4.6.5.

4.8 Alternative B1

This is a continuous study of the system operations under a scenario where the Base Condition (Alternative A1) is adjusted only for drawdown of the Lower Snake River Project to natural river levels, and John Day is operated at natural river level. It was assumed that non-Federal owners would remove their reservoirs from planning, thereby not requiring them to draft to meet load. Non-Federal projects were fixed on the operation resulting from the Base Condition regulation. Federal

projects were allowed to pick up as much of the load lost from removing the Lower Snake and John Day plants while still meeting project non-power requirements.

4.8.1 System Demand

The loads and secondary market limit used in this alternative were the same as Alternative A1, see Section 4.2.1.

4.8.2 Rule Curves

Flood control rule curves in this alternative were the same as Alternative A1. Although the John Day project was drawn down to natural river, it was assumed that flood control space would remain, filling only to retain water during a flood event and evacuating as soon as practicable. The Variable Energy Content curves and Critical Rule Curves used in this alternative were the same as Alternative A1, see Section 4.2.2.

4.8.3 Project Operations

Reservoirs were initialized to the same storage content used in Alternative A1, except at John Day, which was initialized to natural river level. Projects operated to the same non-power requirements used in Alternative A1. Other project operations used in this alternative remained unchanged from Alternative A1 (see Section 4.2.3).

When John Day project operates at natural river level there is no encroachment of the McNary tailwater by John Day pool. Therefore, a new stage vs. tailwater relationship was used in the "B" series of alternatives (see Table 4-12).

Table 4-12. McNary Discharge vs. Stage Relationship Without John Day Encroachment

Discharge, cfs	m^3/s	Elevation, ft	m
96,000	2,718.4	253.4	77.2
200,000	5,663.4	259	78.9
300,000	8,495.1	264	80.5
400,000	11,326.7	267.6	81.6
500,000	14,158.4	270.7	82.5
600,000	16,990.1	273.5	83.4
800,000	22,653.5	278.4	84.9
1,150,000	32,564.4	285.6	87.1

4.8.4 System Operations

The McNary, Lower Granite, and Vernita Bar flow augmentation objectives used in this alternative were the same as Alternative A1. Upper Snake flow augmentation used in this alternative was the same as Alternative A1. The remaining three lower Columbia projects continued to operate within 1 percent of peak efficiency. Spill for juvenile bypassing remained the same as Alternative A1 at non-Federal and at the Federal projects. Spill at Lower Granite, Little Goose, Lower Monumental, Ice Harbor and John Day was removed. For the spill requirements at Bonneville, The Dalles, and McNary, see Section 4.2.4.7. A description of other system operations is found in Section 4.2.4.

4.8.5 BPA Operational Step

All project operations were modeled as in the AER step except as specifically addressed below. PNCA firm Loads based on OY98 projections by the Marketing Analysis, Bulk Power Marketing Branch were used in this study.

A limited secondary market of 9,000 aMW was used in every period, every year.

VECCs were calculated using OY97 PDRs. Although VECC lower limits were eliminated from OY97 refill studies, a lower limit of 379.5 m (1,245 ft) in January; 371.9 m (1,220 ft) February through April; 378.0 m (1,240 ft) in May; and 391.7 m (1,285 ft) in June at Coulee was used in calculating the VECC during period in which the system was generating surplus energy. The Canadian AOP VECCs were based on historical volumes and the Arrow Total method. The VECCs for the Federal projects were based on the Kuehl Moffitt volume forecasts.

Libby was operated in the same manner as in the AER studies with the following exceptions. Libby was operated mid-April through July for protection of sturgeon in all but 20 percent of the driest years (see Flow Objective Table 4-9 for years when no releases were provided) by meeting Bonners Ferry minimum flows. Sturgeon objectives included May 1 through May 9, minimum flows at Bonners Ferry was 424.8 m^3/s (15,000 cfs); May 10 through June 20, Libby outflow reflected a full turbine operation; June 21 through July 11, minimum flow at Bonners Ferry was 311.5 m^3/s (11,000 cfs). The table shows the computed Libby outflow required in the years when sturgeon releases were provided (assuming project discharge during a full turbine operation was equal to 707.9 m^3/s [25,000 cfs]). If the reservoir was above 743.4 m (2,439 ft), the project discharged up to powerhouse capacity, without spill, to support the McNary flow augmentation objectives.

Grand Coulee's operation during the September through December period was the same as in the AER steps. Grand Coulee was operated for power but no lower than the Biological Rule Curves as implemented in the AER January through mid-April. Grand Coulee was operated as low as 381.0 m (1,250.0 ft) 283.5 khm (1,159.1 ksfd) in the second half of April and as low as 390.1 m (1,280.0 ft) or flood control 542.1 khm (2,216.4 ksfd) in May through August to try to meet the McNary flow augmentation objectives. At-site minimum flow was 1,415.5 m^3/s (50,000 cfs) for peaking purposes.

Juvenile bypass fish spill at Federal projects was the same as the AER Step, except that the cap was adjusted as shown below. Lower Snake and John Day spill was removed.

	CAP (cfs)	m^3/s
Bonneville	100,000	2,831.7
The Dalles	230,000	6,512.9
McNary	60,000	1,699.0

4.9 Alternative B2

This alternative is a continuous study of the system operations under a scenario where the Base Condition (Alternative A1) is adjusted for drawdown of the Lower Snake River Project to natural river levels and John Day is operated at natural river level. In this alternative, it was assumed that non-Federal owners would remove their reservoirs from planning, thereby not requiring them to draft to meet load. Non-Federal projects would be fixed on the operation resulting from the

regulation from A1. Flow augmentation on the Columbia River and Snake River was removed, thereby freeing up the reservoir operation for power purposes much of the time. Libby would still provide sturgeon releases. Juvenile bypass spill and 1 percent peak operation is retained. BPA did not model Alternative B2.

4.9.1 System Demand

The system demand or load for this alternative was developed from operating year 1981-82 Critical Period study run by the NWPP. The NWPP study had a 4-year critical period (September 1, 1929 through February 28, 1932). This critical period study was prepared before water budget or any flow augmentation and would yield FELCC shape consistent with removing Columbia River and Snake River flow augmentation. The hydroelectric system in 1981-82 was able to support more load than the current system, but the shape was acceptable. To make the system total load consistent with the current load carrying capability, the 1981-82 loads were decremented by 1,422 aMW.

One year of FELCC values was used for all water conditions. This study reflects coordination between PNCA parties in meeting PNCA FELCC. Therefore, generation from projects owned by non-PNCA parties (Brownlee, Oxbow and Hells Canyon) would not be used to meet PNCA FELCC in these studies. FELCC for periods outside the critical period came from the PNCA Final Regulation. FELCC was created by adding Hydropower Independent generation from 1928-29 to compute system total generation. Then, the system total generation was reduced by 60 years of hydro-independent generation to produce 60 years of FELCC. The secondary market limit used in this alternative were the same as Alternative A1 (see Section 4.2.1).

4.9.2 Rule Curves

Flood control rule curves in this alternative were the same as Alternative A1, except that the system flood control at Dworshak and Brownlee was not shifted to the Grand Coulee project since Snake River flow augmentation was removed. Although the John Day project was drawn down to natural river, it was assumed that flood control space would remain, filling only to retain water during a flood event and evacuating as soon as practicable.

The Variable Energy Content Curves used in this alternative were calculated using Operating Year 1979-80 PDRs, distribution factors and forecast errors which were used in PNCA planning. Canadian Treaty projects were calculated using AOP97 PDRs, the same as Alternative A1. At Grand Coulee the VECC is limited by the Gifford/Inchelium Ferry minimum operating requirements to elevation 371.9 m (1,220 ft). The volume forecast for all projects was based on actual runoff.

In this alternative the CRC were developed in accordance with PNCA 1982 adopted system critical rule curves and published in the Final Regulation for operating year 1981-82. The first year critical curves came from Operating Year 1981-82. The second year critical rule curves came from Operating Year 1980-81, CRC2. The third year critical rule curves came from Operating Year 1979-80, CRC4. The fourth year critical rule curves were set to empty.

4.9.3 Project Operations

Storage reservoirs were initialized to the same elevations as Alternative A1 except Grand Coulee, Hungry Horse, Libby, and Dworshak, which were initialized to elevations 393.2 m (1,290 ft) [639.5 khm (2,614.4 ksfd)]; 1,085.1 m (3,560 ft); 749.5 m (2,459 ft) [614.1 khm (2,510.5 ksfd)]; and 487.7 m (1,600 ft) [248.5 khm (1,016.0 ksfd)], respectively. John Day was initialized to natural river

level. Projects were operated to the same non-power requirements used in Alternative A1, except as noted below. See Section 4.2.3 for a description of other reservoirs.

Libby was operated in proportional draft during September through December to meet December's URC of elevation 734.9 m (2,411.0 ft) [367.4 khm (1,502.2 ksfd)]. In January through mid-April, Libby was operated on minimum flow or flood control. It should be noted that Libby does violate URC to allow Corra Linn's maximum lake level not to exceed the IJC 1938 Order. Libby was operated mid-April through July for protection of sturgeon in all but 20 percent of the lowest observed April-September runoff volumes at Libby by supporting Bonners Ferry minimum flows. Sturgeon releases were not provided in operating years 1928-29, 1930-31, 1935-36, 1936-37, 1939-40, 1940-41, 1943-44, 1944-45, 1969-70, 1977-78, 1978-79, and 1987-88. Sturgeon flow objectives during April 16 through April 30 were to increase flows at Libby so that Bonners Ferry flow was at 424.8 m^3/s (15,000 cfs) on May 1. From May 1 through 19, a minimum flow at Bonners Ferry of 424.8 m^3/s (15,000 cfs) was maintained. From May 20 through June 30 augmentation from Libby tried to attempt to maintain a maximum flow at Bonners Ferry of 991.9 m^3/s (35,000 cfs). From July 1 through July 21 a minimum flow at Bonners Ferry of 311.5 m^3/s (11,000 cfs) was maintained. During July 22 through July 31 a minimum flow at Libby of 113.3 m^3/s (4,000 cfs) was maintained. Libby's maximum outflow from mid-April through August is powerhouse hydraulic capacity without spill. Libby was not operated to support McNary flow objectives.

Hungry Horse was operated for power purpose to meet FELCC. The reservoir storage-elevation relationship reflected 3 percent bank storage. The project operation was regulated to support the Columbia Falls minimum flow of 99.1 m^3/s (3,500 cfs) year round and maximum flow of 127.4 m^3/s (4,500 cfs) October 15 through December 15. The maximum discharge from mid-April through August is powerhouse hydraulic capacity plus 85.0 m^3/s (3,000 cfs) spill.

Grand Coulee was operated for power purpose to meet FELCC. At-site minimum flow is equal to 849.5 m^3/s (30,000 cfs). The Vernita Bar minimum flows were supported by flow augmentation from Grand Coulee. The reservoir was operated to a drawdown limit of 0.4 m (1.3 ft) per day. A summer recreation minimum elevation of 391.7 m (1,285 ft) was observed in June and July. In May the pool was kept above elevation 378.0 m (1,240 ft) for pumping purposes into Banks Lake for irrigation.

Brownlee was operated to meet flood control, 566.3 m^3/s (20,000 cfs) maximum flow in October and 254.9 m^3/s (9,000 cfs) maximum flow in November. This operation is imposed over the 60-year fixed operation used in PNCA planning.

Dworshak was allowed to proportional draft to meet FELCC September 1 through May 31. For recreation during June through August, the reservoir was held above elevation 486.2 m (1,595 ft). In October, the maximum discharge was equal to inflow plus 36.8 m^3/s (1,300 cfs).

Since John Day was operated at natural river it did not encroach on the tailwater at McNary. In this alternative McNary used the same stage vs. tailwater relationship as in Alternative B1 (see Section 4.8.3).

4.9.4 System Operations

The McNary and Lower Granite flow augmentation objectives were removed from this alternative and the Vernita Bar flow augmentation objectives were the same as Alternative A1. Upper Snake

flow augmentation was not adjusted to release 52.7 khm (427 KAF). The three remaining lower Columbia River projects continued to operate within 1 percent of peak efficiency and spill for juvenile bypassing remained the same as Alternative A1 at non-Federal projects, but changed at the Federal projects. Spill at Lower Granite, Little Goose, Lower Monumental, Ice Harbor, and John Day was removed. For the spill requirements at Bonneville, The Dalles, and McNary, see Section 4.2.4.7. A description of other system operations is found in Section 4.2.4.

4.10 Alternative C1

Alternative C1 is a continuous study of the system operations under a scenario where the Base Condition (Alternative A1) was adjusted for drawdown of the Lower Snake River Project to natural river levels and John Day was operated at spillway crest. It was assumed that non-Federal owners would remove their reservoirs from planning, thereby not requiring them to draft to meet load. Non-Federal projects were fixed on the operation resulting from the Base Condition regulation. Federal projects were allowed to pick up as much of the load lost from breaching the Lower Snake plants and operating John Day at spillway level as possible while still meeting project non-power requirements.

4.10.1 System Demand

The loads and secondary market used in this alternative were the same as Alternative A1 (see Section 4.2.1).

4.10.2 Rule Curves

Flood control rule curves in this alternative were the same as Alternative A1. Although John Day project was drawn down to spillway level, it was assumed that flood control space would remain, filling only to retain water during a flood event and evacuating as soon as practicable. The Variable Energy Content curves and Critical Rule Curves used in this alternative were the same as Alternative A1 (see Section 4.2.2).

4.10.3 Project Operations

Reservoirs were initialized to the same storage content used in Alternative A1, except at John Day, which was initialized to elevation 65.5 m (215 ft). Projects operated to the same non-power requirements used in Alternative A1. Other project operations used in this alternative remained unchanged from Alternative A1 (see Section 4.2.3).

When John Day project operates at spillway level there is no encroachment of the McNary tailwater by John Day pool. Therefore, a new stage vs. tailwater relationship, was used for the "C" series of alternatives (see Table 4-11).

4.10.4 System Operations

The McNary, Lower Granite, and Vernita Bar flow augmentation objectives used in this alternative were the same as Alternative A1. Upper Snake flow augmentation used in this alternative was the same as Alternative A1. The four lower Columbia projects continued to operate within 1 percent of peak efficiency. Spill for juvenile bypassing remained the same as Alternative A1 at non-Federal and at the Federal projects. Spill at Lower Granite, Little Goose, Lower Monumental, and Ice

Harbor was removed. For the spill requirements at Bonneville, The Dalles, John Day and McNary, see Section 4.2.4.7. A description of other system operations is found in Section 4.2.4.

4.10.5 BPA Operational Step

The operational step was performed the same as Alternative B1 (shown in Section 4.8.5) except that a John Day spill cap of 1,699.9 m^3.s (60,000 cfs) was used.

4.11 Alternative C2

This alternative is a continuous study of the system operations under a scenario where the Base Condition (Alternative A1) was adjusted only for drawdown of the Lower Snake River Project to natural river levels and John Day was operated at spillway crest. Flow augmentation on the Columbia River and Snake River are removed, thereby freeing up the reservoir operation for power purposes much of the time. Libby would still provide sturgeon releases. Juvenile bypass spill and 1 percent peak operation is retained. BPA did not model this alternative.

4.11.1 System Demand

The system demand or load for this alternative was developed from the operating year 1981-82 Critical Period study run by the NWPP as discussed in Section 4.9.1. The secondary market limit used in this alternative were the same as Alternative A1 (see Section 4.2.1).

4.11.2 Rule Curves

Flood control rule curves in this alternative were the same as Alternative A1, except that the system flood control at Dworshak and Brownlee was not shifted to Grand Coulee project since Snake River flow augmentation was removed. Although John Day project was drawn down to spillway level, it was assumed that flood control space would remain, filling only to retain water during a flood event and evacuating as soon as practicable.

The Variable Energy Content Curves used in this alternative were calculated using Operating Year 1979-80 PDRs and distribution factors and forecast errors which were used in PNCA planning. Canadian Treaty projects were calculated using AOP97 PDRs, the same as Alternative A1. At Grand Coulee the VECC was limited by the Gifford/Inchelium Ferry to elevation 371.9 m (1,220 ft). The volume forecast for all projects are based on actual runoff.

4.11.3 Project Operations

Storage reservoirs were initialized to the same elevations as Alternative A1 except Grand Coulee, Hungry Horse, Libby, Dworshak and John Day which were initialized to elevations 393.2 m (1,290 ft) (639.5 khm [2,614.4 ksfd]); 1,085.1 m (3,560 ft); 749.5 m (2,459 ft) [614.1 khm (2,510.5 ksfd)]; 487.7 m (1,600 ft) [248.5 khm (1,016.0 ksfd)]; and 65.5 m (215 ft), respectively. Projects operated to the same non-power requirements used in Alternative A1, except as noted below. See Section 4.2.3 for a description of other reservoirs.

Libby was operated in proportional draft during September through December to meet Decembers URC of elevation 734.9 m (2,411.0 ft) [367.4 khm (1,502.2 ksfd)]. In January through mid-April, Libby was operated on minimum flow or flood control. It should be noted that Libby does violate URC to allow Corra Linn's maximum lake level not to exceed the IJC 1938 Order. Libby was operated mid-April through July for protection of sturgeon in all but 20 percent of the worst

observed April-September runoff volumes at Libby by supporting Bonners Ferry minimum flows. Sturgeon releases were not provided in 1928-29, 1930-31, 1935-36, 1936-37, 1939-40, 1940-41, 1943-44, 1944-45, 1969-70, 1977-78, 1978-79, and 1987-88. Sturgeon flow objectives during April 16 through April 30 were to increase flows at Libby so that Bonners Ferry flow is at 424.8 khm (15,000 cfs) on May 1. From May 1 through May 19, a minimum flow at Bonners Ferry of 424.8 khm (15,000 cfs) was maintained. From May 20 through June 30 augmentation from Libby to maintain a maximum flow at Bonners Ferry of 991.1 m^3/s (35,000 cfs). From July 1 through July 21 a minimum flow at Bonners Ferry of 311.5 m^3/s (11,000 cfs) was maintained. During July 22 through July 31 a minimum flow at Libby of 113.3 m^3/s (4,000 cfs) was maintained. Libby's maximum outflow from mid-April through August is powerhouse hydraulic capacity without spill. Libby was not operated to support McNary flow objectives.

Hungry Horse was operated for power purposes to meet FELCC. The reservoir storage-elevation relationship reflected 3 percent bank storage. The project operation was regulated to support the Columbia Falls minimum flow of 99.1 m^3/s (3,500 cfs) year round and maximum flow of 127.4 m^3/s (4,500 cfs) October 15 through December 15. The maximum discharge from mid-April through August is powerhouse hydraulic capacity plus 85.0 m^3/s (3,000 cfs) spill.

Grand Coulee was operated for power purposes to meet FELCC. At-site minimum flow is equal to 849.5 m^3/s (30,000 cfs). The Vernita Bar minimum flows were supported by flow augmentation from Grand Coulee. The reservoir observed a drawdown limit of 0.4 m (1.3 ft) per day. A summer recreation minimum elevation of 391.7 m (1,285 ft) was observed in June and July. In May the pool was kept above elevation 378.0 m (1,240 ft) for pumping purposes into Banks Lake for irrigation.

Brownlee was operated to meet flood control, 566.3 m^3/s (20,000 cfs) maximum flow in October and 254.9 m^3/s (9,000 cfs) maximum flow in November. This operation is imposed over the 60-year fixed operation used in PNCA planning.

Dworshak was allowed to draft to meet FELCC September 1 through May 31. For recreation during June through August, the reservoir was held above elevation 486.2 m (1,595 ft). In October, the maximum discharge is equal to inflow plus 36.8 m^3/s (1,300 cfs).

Since John Day is operated at spillway level it did not encroach on the tailwater at McNary. This alternative used the same stage vs. tailwater relationship in Alternative B1 (see Section 4.8.3).

4.11.4 System Operations

The McNary and Lower Granite flow augmentation objectives were removed from this alternative and the Vernita Bar flow augmentation objectives were the same as Alternative A1. Upper Snake flow augmentation was not adjusted to release 52.7 khm (427 KAF). The four lower Columbia River projects continued to operate within 1 percent of peak efficiency and spill for juvenile bypassing remained the same as Alternative A1 at non-Federal projects, but changed at the Federal projects. Spill at Lower Granite, Little Goose, Lower Monumental, and Ice Harbor was removed. For the spill requirements at Bonneville, The Dalles, John Day, and McNary, see Section 4.2.4.7. A description of other system operations is found in Section 4.2.4.

5. Comparison of Results

5.1 Introduction

The results of computer simulations of the alternatives described in Chapter 4 are discussed in this chapter and compared against the Base Condition or no action Alternative A1. Three general categories of results were compared, system generation, reservoir elevations and flows.

Regulated hydroelectric projects in the northwest contribute to the system generation along with independent hydroelectric projects and thermal resources. Each alternative modeled provides different amounts of system generation depending on the non-power requirements assumed in each alternative investigated. At the end of this chapter is Table 5-1 which shows the 60-year average system generation for the regulated hydroelectric projects modeled in the PNW area. The table contains the average system generation by alternative for each period and the 60-year average annual system generation. Table 5-2 illustrates the difference in system generation compared to the Base Condition or Alternative A1. Also provided in Table 5-3 is the contribution of average generation from the four lower Snake River hydropower facilities—Lower Granite (LWG), Little Goose (LGS), Lower Monumental (LMN), and Ice Harbor (IHB). Values found in all three tables are in aMW.

Reservoirs draft and fill based on the PNW load, non-power requirements, and available stream flows. Table 5-4 illustrates the 60-year average reservoir elevations for each alternative investigated, by periods. The average annual reservoir elevation is also provided on the far right. Information is limited to the four major Federal storage projects, Libby (LIB), Hungry Horse (HGH), Grand Coulee (GCL), and Dworshak (DWR). In addition, the difference in average elevation compared the Base Condition is illustrated in Table 5-5 for each alternative. Values found in both tables are in feet.

As a result of the non-power requirements modeled, the 60 years of natural streamflows are regulated on the Columbia and Snake Rivers. Biological objectives are described in the Salmon Biological Opinion for Lower Granite and McNary. Table 5-6 and 5-7 show the 60-year average regulated flow for each alternative by period for Lower Granite and McNary, respectively. Also included in these two tables are the 60-year natural streamflows. The difference in regulated flows compared to the Base Condition is illustrated in Tables 5-8 and 5-9, respectively. Values found in all four tables are in cfs.

Displayed in Tables 5-10 and 5-11 are the number of years out of 60 that the Salmon Biological Opinion flow objectives were met at Lower Granite and McNary, respectively. The number of years met for the natural flow and the accomplishments of the regulated flow for each alternative are provided in these tables. There are no flow objectives in the Salmon Biological Opinion September through March.

Below is a discussion of the accomplishments of each alternative and a comparison of results from the Base Condition.

5.2 Alternative A1 Results

5.2.1 System Generation

The average annual system generation for regulated hydroelectric plants in the model was 14,038 aMW. The highest periods of system generation were in the last part of April, May, and June which coincide with the spring runoff and the spring flow augmentation period. In these periods the system generated

16,890 aMW, 18,729 aMW, and 18,834 aMW, respectively. During the peak load period in January the system generated 16,800 aMW. The periods of lowest system generation were in September at 9,466 aMW and October at 9,520 aMW.

5.2.2 Reservoir Elevations

The 60-year average annual reservoir elevations at Libby, Hungry Horse, Grand Coulee, and Dworshak were 732.9 m (2,404.5 ft); 1,073.9 m (3,523.4 ft); 386.9 m (1,269.5 ft); and 469.3 m (1,539.6 ft), respectively. Reservoirs drafted to their lowest point at the end of the flood control evacuation period in March or April to elevation 716.5 m (2,350.8 ft); 1,065.4 m (3,495.7 ft); 376.4 m (1,235.0 ft); and 460.7 m (1,511.5 ft), respectively. They achieved their highest point at the end of the flood control refill period in July to elevations 745.0 m (2,444.2 ft); 1,082.7 m (3,552.2 ft); and 392.2 m (1,286.9 ft), respectively, with the exception of Dworshak, which peaked in June at elevation 475.3 m (1,580.0 ft).

5.2.3 Flows

Flows from the Snake River are monitored at Lower Granite where flow objectives are identified in the Salmon Biological Opinion. The natural flow at Lower Granite increases from 586.2 m^3/s (20,701 cfs) in the last part of August to a peak of 3,440.0 m^3/s (121,483 cfs) in May and decreases back down to the lowest flow in the last part of August. In Alternative A1 the regulated flow increases from 672.6 m^3/s (23,751 cfs) in September to a peak of 3,114.4 m^3/s (109,972 cfs) in May and decreases back down to 672.6 m^3/s (23,751 cfs) in September with the exception of November where the regulated flow is the lowest at 555.0 m^3/s (19,598 cfs).

The Salmon Biological Opinion has identified flow objectives at McNary to control the Columbia River. At McNary, the natural flow increases from 2,349.1 m^3/s (82,959 cfs) in October to the peak flow of 13,123.8 m^3/s (463,462 cfs) in June with the exception of January which decreases slightly from the December streamflow. Natural flows decrease from the June peak down to the lowest flow in October. In Alternative A1, the regulated flow increased from 2,867.2 m^3/s (101,254 cfs) in September to a peak of 7,921.4 m^3/s (279,741 cfs) in June and decreased back down to the lowest flow in September, with the exception of January where the regulated flow was 5,376.6 m^3/s (189,872 cfs).

The Salmon Biological Opinion regulated flow objective at Lower Granite in Alternative A1 was met in 27 years during the last part of April, in 39 years during May, in 39 years during June, in 18 years in July, and in 4 years during the first part of August. Alternative A1 did not meet the objectives in any year during the last part of August. Using the natural flows compared to the Lower Granite flow objectives, they were met 24 years in the last part of April, 44 years in May, 44 years in June, 11 years in July, and no years in the first or last part of August.

At McNary, the Salmon Biological Opinion flow objectives were met in 40 years during the last part of April, in 57 years during May, in 28 years during June, in 5 years during July, in 1 year during the first part of August, and in no years during the last part of August. The natural flows met these objectives in 42 years during the last part of April, in 60 years during May, in 60 years during June, in 29 years during July, in 1 year during the first part of August, and in none during the last part of August.

5.3 Alternative A2 Impacts

5.3.1 System Generation

The average annual system generation for regulated hydroelectric plants in the model for Alternative A2 was 14,108 aMW. The highest period of system generation was in the last part of April, May, and June which coincide with the spring runoff and the spring flow augmentation period. In these periods the system generated 17,129 aMW; 19,049 aMW; and 19,139 aMW, respectively. During the peak load period in January the system generated 16,803 aMW. The periods of lowest system generation were in September at 9,467 aMW and October at 9,533 aMW.

In this alternative, spill for juvenile bypassing was eliminated at Lower Granite, Little Goose, Lower Monumental, and McNary. When compared with Alternative A1, the system generation was identical with the exception of the first part of April, the last part of April, May, and June when spill was eliminated. This allowed more water to be available for generation and increased the project annual generation by 10 to 20 aMW. The annual system generation increased by 71 aMW.

5.3.2 Reservoir Elevations

The 60-year average annual reservoir elevations at Libby, Hungry Horse, Grand Coulee and Dworshak were 732.9 m (2,404.4 ft); 1,073.9 m (3,523.3 ft); 386.9 m (1,269.5 ft); and 469.3 m (1,539.6 ft), respectively. Reservoirs drafted to their lowest point at the end the flood control evacuation period in March or April to elevation 716.5 m (2,350.7 ft); 1,065.4 m (3,495.5 ft); 376.4 m (1,235.0 ft); and 460.7 m (1,511.5 ft), respectively. They achieved their highest point at the end of the flood control refill period in July to elevations 744.9 m (2,444.0 ft); 1,082.7 m (3,552.2 ft); and 392.2 m (1,286.9 ft), with the exception of Dworshak, which peaked in June at elevation 475.3 m (1,580.0 ft). Reservoir elevations were almost identical when compared to Alternative A1. The maximum changes to the average reservoir elevations were 0.3 ft at Hungry Horse.

5.3.3 Flows

In Alternative A2 the regulated flow at Lower Granite increases from 672.6 m^3/s (23,751 cfs) in September to a peak of 3,114.4 m^3/s (109,975 cfs) in May and decreases back down to 672.6 m^3/s (23,751 cfs) in September with the exception of November where the regulated flow is 554.6 m^3/s (19,584 cfs). When compared to Alternative A1, the regulated flow at Lower Granite is almost identical showing a maximum difference of 0.7 m^3/s (23 cfs) in any one period.

At McNary, in Alternative A2, the regulated flows increased from 2,865.2 m^3/s (101,183 cfs) in September to a peak of 7,910.9 m^3/s (279,372 cfs) in May and back down to the lowest flow in September with the exception of January where the regulated flow was 5,379.7 m^3/s (189,984 cfs). The largest difference in regulated flow, when compared to Alternative A1, was in the last part of April, May, and June where the difference was between 8.5 m^3/s (300 cfs) and 19.8 m^3/s (700 cfs). Other periods varied less than 4.2 m^3/s (150 cfs).

The Salmon Biological Opinion regulated flow objective at Lower Granite in Alternative A2 was met in 27 years during the last part of April, in 40 years during May, in 39 years during June, in 18 years in July, in 4 years during the first part of August, and in no years during the last part of August.

In Alternative A2 at McNary, the Salmon Biological Opinion flow objectives were met in 40 years during the last part of April, in 57 years during May, in 28 years during June, in 5 years during July, in 1 year during the first part of August, and in no years during the last part of August.

5.4 Alternative A3 Impacts

5.4.1 System Generation

The average annual system generation for regulated hydroelectric plants in the model for Alternative A3 was 12,771 aMW. The highest periods of system generation were in May and June which coincide with the spring runoff and the spring flow augmentation period. In these periods the system generated 16,314 aMW and 16,703 aMW, respectively. During the peak load period in January the system generated 15,987 aMW. The periods of lowest system generation were in September at 9,046 aMW and October at 8,953 aMW.

In this alternative, the Lower Snake River Project was drawn down to natural river level and generation from these plants was eliminated. Columbia River and Snake River flow augmentation remained unchanged. The reduction in system generation is mainly due to this effect. The annual generation from these plants in Alternative A1 is 1,246 aMW, ranging from 2,400 aMW in May to 500 aMW in November. There was some ability of the system to make up this lost generation at other plants.

5.4.2 Reservoir Elevations

The 60-year average annual reservoir elevations at Libby, Hungry Horse, Grand Coulee, and Dworshak were 732.6 m (2,403.5 ft); 1,073.5 m (3,522.0 ft); 386.2 m (1,267.2 ft); and 468.9 m (1,538.3 ft), respectively. Reservoirs drafted to their lowest point at the end of the flood control evacuation period in March or April to elevations 716.5 m (2,350.8 ft); 1,064.6 m (3,492.8 ft); 376.4 m (1,234.8 ft); and 460.6 m (1,511.1 ft), respectively. They achieved their highest point at the end of the flood control refill period in July to elevations 745.0 m (2,444.2 ft); 1,082.7 m (3,552.1 ft); 392.2 m (1,286.9 ft); and 475.9 m (1,561.0 ft), respectively.

When compared to Alternative A1, Libby drafted approximately 4 ft deeper September through November to help replace generation lost from the drawdown of the Lower Snake River Project. In other periods it was within 0.0 m (0.1 ft) of the elevations in Alternative A1. Hungry Horse drafted 0.3 m (0.9 ft) deeper September through December and approximately 0.9 m (3 ft) deeper January through April. The reservoir elevations May through August were 0.1 m (0.3 ft) deeper. The maximum changes to the average reservoir elevations in other periods were 0.1 m (0.3 ft). Grand Coulee drafted 0.3 m (0.9 ft) deeper September through December and approximately 0.9 m (3 ft) to 2.7 m (9 ft) deeper January through April. Dworshak drafted 0.6 m (2 ft) deeper July through December and 0.2 m (0.6 ft) deeper January through June. Deeper drafts are the result of projects attempting to replace generation lost due to drawdown of the four dams in the Lower Snake River Project.

5.4.3 Flows

In Alternative A3 the regulated flow at Lower Granite increases from 672.6 m^3/s (23,751 cfs) in September to a peak of 3,114.8 m^3/s (109,999 cfs) in May and decreases back down to 672.6 m^3/s (23,751 cfs) in September with the exception of November where the regulated flow is 576.8 m^3/s (20,371 cfs). When compared to Alternative A1, the regulated flow at Lower Granite is within the maximum differences of 21.9 m^3/s (773 cfs); 40.6 m^3/s (1,435 cfs); and 15.2 m^3/s (537 cfs) in November,

the first part of April, and July, respectively. Other periods varied between 4.2 m^3/s (150 cfs) and 8.5 m^3/s (300 cfs).

At McNary, in Alternative A3, the regulated flows increased from 2,916.8 m^3/s (103,006 cfs) in September to a peak of 7,900.5 m^3/s (279,002 cfs) in May and back down to the lowest flow in September, with the exception of January and March where the regulated flow was 5,495.2 m^3/s (194,060 cfs) and 4,467.4 m^3/s (157,766 cfs), respectively. When compared to Alternative A1, the regulated flows increased from the last part of August to November between 42.5 m^3/s (1,500 cfs) and 99.1 m^3/s (3,500 cfs). December had a 70.8 m^3/s 2,500 cfs) decrease in regulated flow. From March through May the regulated flows increased from 19.8 m^3/s (700 cfs) to 254.9 m^3/s (9,000 cfs).

The Salmon Biological Opinion regulated flow objective at Lower Granite in Alternative A3 was met in 27 years during the last part of April, in 41 years during May, in 41 years during June, in 21 years in July, in 4 years during the first part of August, and in no years during the last part of August.

In Alternative A3 at McNary, the Salmon Biological Opinion flow objectives were met in 40 years during the last part of April, in 57 years during May, in 35 years during June, in 5 years during July, in 1 year during the first part of August, and in no years during the last part of August.

5.5 Alternative A5 Impacts

5.5.1 System Generation

The average annual system generation for regulated hydroelectric plants in the model for Alternative A5 was 12,805 aMW. The highest periods of system generation were in May and June which coincide with the spring runoff and the spring augmentation period. In these periods the system generated 16,078 aMW and 16,538 aMW, respectively. During the peak load period in January the system generated 16,230 aMW which was as high as the May and June periods. The periods of lowest system generation were in the last part of August at 9,699 aMW, September at 9,317 aMW, and October at 9,107 aMW.

In this alternative, the Lower Snake River Project was drawn down to natural river level, and generation from these plants was eliminated. In addition, the Snake River flow augmentation was removed. The reduction in system generation is mainly due to these projects being drawn down to natural river level. The annual generation from these plants in Alternative A1 is 1,246 aMW, ranging from 2,400 aMW in May to 500 aMW in November. Eliminating the Snake River flow augmentation allowed regulation of Dworshak storage for power, decreasing the May and June system generation and increasing the December, January, and February system generation. Elimination of the Snake River flow augmentation allowed the system to gain 34 aMW of annual generation, the difference between A3 and A5. There was some ability of the system to make up this lost generation at other plants.

5.5.2 Reservoir Elevations

The 60-year average annual reservoir elevations at Libby, Hungry Horse, Grand Coulee, and Dworshak were 732.7 m (2,403.8 ft); 1,073.6 m (3,522.3 ft); 386.3 m (1,267.5 ft); and 466.0 m (1,528.9 ft), respectively. Reservoirs drafted to their lowest point at the end the flood control evacuation period in March or April to elevations 716.5 m (2,350.8 ft); 1,064.8 m (3,493.4 ft); 376.3 m (1,234.5 ft); and 445.5 m (1,461.6 ft), respectively. They achieved their highest point at the end of the flood control refill period in July to elevations 745.0 m (2,444.1 ft); 1,082.6 m (3,551.7 ft); 392.2 m (1,286.7 ft); and 485.3 m (1,592.3 ft), respectively.

When compared to Alternative A1, Libby drafted approximately 0.9 m (3 ft) deeper September through November to help replace generation lost from the drawdown of the Lower Snake River Project. In other periods it was within 0.0 m (0.1 ft) of the elevations in Alternative A1. Hungry Horse drafted 0.1 m (0.3 ft) deeper September through December and approximately 0.9 m (3 ft) deeper January through April. The reservoir elevations May through August were 0.2 m (0.5 ft) deeper. The maximum changes to the average reservoir elevations in other periods were 0.1 m (0.3 ft). Grand Coulee drafted 0.1 m (0.4 ft) deeper September through December and approximately 0.6 m (2 ft) to 2.4 m (8 ft) deeper January through April. Dworshak had significant reservoir elevation differences compared to Alternative A1 due to the removal of Snake River flow augmentation. From November through May the project drafted between 6.1 m (20 ft) and 17.7 m (58 ft) deeper. From June through October the reservoir was 3.0 m (10 ft) to 17.7 m (58ft) higher. The average annual reservoir elevation at Dworshak was lowered by 3.3 m (10.7 ft). Deeper drafts are the result of projects attempting to replace generation lost due to drawdown.

5.5.3 Flows

In Alternative A5, the regulated flow at Lower Granite increases from 600.2 m^3/s (21,196 cfs) in the last part of August to a peak of 2,953.9 m^3/s (104,316 cfs) in May and decreases back down to the lowest point in the last part of August with the exception of September, when the regulated flow is 981.6 m^3/s (34,666 cfs). When compared to Alternative A1, the regulated flow at Lower Granite increased in September through February from 566.0 m^3/s (2,000 cfs) to 311.5 m^3/s (11,000 cfs) and decreased in March through August from 14.2 m^3/s (500 cfs) to 339.8 m^3/s (12,000 cfs).

At McNary, in Alternative A5, the regulated flows increased from 3,073.1 m^3/s (108,527 cfs) in October to a peak of 7,760.4 m^3/s (274,055 cfs) in May and back down to the lowest flow in October with the exception of January and March where the regulated flow was 5,598.8 m^3/s (197,718 cfs) and 4,464.1 m^3/s (157,649 cfs), respectively. When compared to Alternative A1, the regulated flows increased from September to February between 113.3 m^3/s (4,000 cfs) and 311.5 m^3/s (11,000 cfs) and decreased from March to August between 85.0 m^3/s (3,000 cfs) and 453.1 m^3/s (16,000 cfs).

The Salmon Biological Opinion regulated flow objective at Lower Granite in Alternative A5 was met in 19 years during the last part of April, in 34 years during May, in 39 years during June, in 11 years in July, and in no years during the first or last part of August.

In Alternative A5 at McNary, the Salmon Biological Opinion flow objectives were met in 37 years during the last part of April, in 54 years during May, in 29 years during June, in 4 years during July, in 1 year during the first part of August, and in no years during the last part of August.

5.6 Alternative A6a Impacts

5.6.1 System Generation

The average annual system generation for regulated hydroelectric plants in the model for Alternative A6a was 14,064 aMW. The highest periods of system generation were in the last part of April, May, and June, which coincide with the spring runoff and the spring flow augmentation period. In these periods the system generated 17,221 aMW; 18,544 aMW; and 18,879 aMW, respectively. During the peak load period in January the system generated 16,860 aMW. The periods of lowest system generation were in September at 9,495 aMW and October at 9,535 aMW.

This alternative was adjusted to reflect an additional 123.3 khm (1.0 MAF) of upper Snake storage for flow augmentation, a total of 176.0 khm (1,427 KAF). When compared with Alternative A1, this allowed more water from the upper Snake River Basin to be available for flow augmentation during the spring and summer when Lower Snake and Columbia River projects are spilling water to bypass juveniles downstream. System generation decreased during this period because more flow was subject to spill. This decreases the average annual system generation by 26 aMW.

5.6.2 Reservoir Elevations

The 60-year average annual reservoir elevations at Libby, Hungry Horse, Grand Coulee, and Dworshak were 723.8 m (2,404.3 ft); 1,073.7 m (3,522.7 ft); 386.8 m (1,269.1 ft); and 469.1 m (1,539.2 ft), respectively. Reservoirs drafted to their lowest point at the end the flood control evacuation period in March or April to elevations 716.5 m (2,350.8 ft); 1,065.2 m (3,494.8 ft; 375.6 m (1,232.2 ft); and 460.4 m (1,510.5 ft). They achieved their highest point at the end of the flood control refill period in July to elevations 745.0 m (2,444.2 ft); 1,082.5 m (3,551.5 ft); and 392.1 m (1,286.5 ft), with the exception of Dworshak, which peaked in June at elevation 485.0 m (1,591.3 ft).

When compared to Alternative A1, Libby, Hungry Horse, and Grand Coulee drafted less than 0.3 m (1.0 ft) deeper through the operating year. Dworshak drafted less than 1.2 m (4.0 ft) deeper from August through December. From April through June the reservoir was 0.9 m (3.0 ft) to 4.9 m (16 ft) higher. Deeper drafts are the result of projects attempting to replace generation lost due to drawdown.

5.6.3 Flows

In Alternative A6a the regulated flow at Lower Granite increases from 642.2 m^3/s (22,679 cfs) in September to a peak of 3,133.6 m^3/s (110,663 cfs) in May and decreases back down to the lowest point in September, with the exception of November where the regulated flow is 535.9 m^3/s (18,925 cfs). When compared to Alternative A1, the regulated flow at Lower Granite decreased in October through the first part of April from 5.7 m^3/s (200 cfs) to 48.1 m^3/s (1,700 cfs) and increased in the last part of April through September from 14.2 m^3/s (500 cfs) to 2.8 m^3/s (7,700 cfs).

At McNary, in Alternative A6a, the regulated flows increased from 2,844.7 m^3/s (100,459 cfs) in September to a peak of 7,866.6, m^3/s (277,808 cfs) in May and back down to the lowest flow in September, with the exception of February and March where the regulated flow was 4,820 m^3/s (170,218 cfs) and 4,628.3 m^3/s (163,448 cfs), respectively. When compared to Alternative A1, the regulated flow decreased 54.7 m^3/s (1,933 cfs) in May and 26.5 m^3/s (936 cfs) in February. The regulated flows increased 113.1 m^3/s (3,994 cfs) in the first part of August; 243.7 m^3/s (8,607 cfs) in the last part of August; 140.5 m^3/s (4,963 cfs) in the last part of April; 84.2 m^3/s (2,975 cfs) in June; and 59.3 m^3/s (2,095 cfs) in July. In other periods the change in flow was less than 22.7 m^3/s (800 cfs).

The Salmon Biological Opinion regulated flow objective at Lower Granite in Alternative A6a was met in 29 years during the last part of April, in 43 years during May, in 46 years during June, in 19 years in July, in 6 years during the first part of August, and in 2 years during the last part of August.

In Alternative A6a at McNary, the Salmon Biological Opinion flow objectives were met in 47 years during the last part of April, in 54 years during May, in 39 years during June, in 5 years during July, in 1 year during the first part of August, and in no years during the last part of August.

5.7 Alternative A6b Impacts

5.7.1 System Generation

The average annual system generation for regulated hydroelectric plants in the model for Alternative A6b was 14,028 aMW. The highest periods of system generation were in the last part of April, May, and June, which coincide with the spring runoff and the spring augmentation period. In these periods the system generated 17,346 aMW; 18,578 aMW; and 18,756 aMW, respectively. During the peak load period in January the system generated 16,840 aMW. The periods of lowest system generation were in September at 9,412 aMW and October at 9,504 aMW.

This alternative was not adjusted to reflect upper Snake storage for flow augmentation. When compared to Alternative A1, this allowed less water from the upper Snake River Basin to be available for flow augmentation during the spring and summer. This slightly decreased the average annual system generation by 10 aMW.

5.7.2 Reservoir Elevations

The 60-year average annual reservoir elevations at Libby, Hungry Horse, Grand Coulee, and Dworshak were 732.8 m (2,404.3 ft); 1,073.7 m (3,522.6 ft); 386.9 m (1,269.2 ft); and 466.3 m (1,530.0 ft), respectively. Reservoirs drafted to their lowest point at the end the flood control evacuation period in March or April to elevations 716.5 m (2,350.8 ft); 1,065.1 m (3,494.5 ft); 375.6 m (1,232.2 ft); and 458.8 m (1,505.3 ft). They achieved their highest point at the end of the flood control refill period in July to elevations 745.0 m (2,444.2 ft); 1,082.5 m (3,551.4 ft); and 392.2 m (1,286.9 ft), with the exception of Dworshak, which peaked in June at elevation 480.5 m (1,576.6 ft).

When compared to Alternative A1, Libby drafted less than 0.3 m (1.0 ft) deeper and showed no change from December through July. Hungry Horse drafted less than 0.3 m (1.0 ft) deeper in all periods. Grand Coulee drafted less than 0.3 m (1.0 ft) deeper in all periods with the exception of April, when it drafted 0.9 m (2.8 ft) deeper. Dworshak drafted between 3.0 m (10 ft) and 4.6 m (15 ft) deeper from August through January. From February through July the reservoir drafted between 1.2 m (4.0 ft) and 2.4 m (8.0 ft) deeper. The average annual reservoir elevation at Dworshak was 3.0 m (9.8 ft) deeper. Deeper drafts are the result of other projects attempting to replace generation lost due to drawdown.

5.7.3 Flows

In Alternative A6b the regulated flow at Lower Granite increases from 654.3 m^3/s (23,105 cfs) in September to a peak of 3,119.4 m^3/s (110,161 cfs) in May and decreases back down to 654.3 m^3/s (23,105 cfs) in September, with the exception of November where the regulated flow is 583.6 m^3/s (20,611 cfs). When compared to Alternative A1, the regulated flow at Lower Granite increased 29.1 m^3/s (1,029 cfs) in the first part of August; 28.7 m^3/s (1,013 cfs) in November; and 27.6 m^3/s (974 cfs) in December. The regulated flows decreased 78.1 m^3/s (2,534 cfs) in the last part of August and 43.8 m^3/s (1,547 cfs) in July. Other periods changed less than 18.4 m^3/s (650 cfs).

At McNary, in Alternative A6b, the regulated flows increased from 2,836.7 m^3/s (100,177 cfs) in September to a peak of 7,861.1 m^3/s (277,613 cfs) in May and back down to the lowest flow in September with the exception of January and March where the regulated flow was 5,404.9 m^3/s (190,871 cfs) and 4,647.7 m^3/s (164,132 cfs), respectively. When compared to Alternative A1, the regulated flows increased 27.6 m^3/s (973 cfs) in November; 28.3 m^3/s (999 cfs) in January; and 200.7 m^3/s (7,088 cfs) in the last part of April. The regulated flows decreased 41.4 m^3/s (1,461 cfs) in the last part of August;

30.5 m^3/s (1,077 cfs) in September; 33.0 m^3/s (1,166 cfs) in February; 60.3 m^3/s (2,128 cfs) in May; and 29.3 m^3/s (1,036 cfs) in July. Other periods changed less than 21.2 m^3/s (750 cfs).

The Salmon Biological Opinion regulated flow objective at Lower Granite in Alternative A6b was met in 28 years during the last part of April, in 39 years during May, in 40 years during June, in 13 years in July, in 3 years during the first part of August, and in no years during the last part of August.

In Alternative A6b at McNary, the Salmon Biological Opinion flow objectives were met in 47 years during the last part of April, in 54 years during May, in 31 years during June, in 5 years during July, in 1 year during the first part of August, and in no years during the last part of August.

5.8 Alternative B1 Impacts

5.8.1 System Generation

The average annual system generation for regulated hydroelectric plants in the model for Alternative B1 was 11,647 aMW as shown in Table 5-1. The highest periods of system generation were in May and June which coincide with the spring runoff and the spring flow augmentation period. In these periods the system generated 14,693 aMW and 15,114 aMW, respectively. During the peak load period in January the system generated 14,535 aMW. The periods of lowest system generation were in the last part of August at 9,835 aMW; September at 8,703 aMW; October at 8,519 aMW; and November at 9,377 aMW.

In this alternative the Lower Snake River Project and John Day were drawn down to natural river level causing generation from these plants to be eliminated. Columbia River and Snake River flow augmentation remained unchanged. The reduction in system generation is mainly due to these projects being drawn down to natural river level. The annual generation from these plants in Alternative A1 is 2,416 aMW, ranging from 4,102 aMW in May to 1,270 aMW in the last part of August. McNary project was able to increase its average annual generation without the John Day project tailwater encroachment by 72 aMW. The net change in system generation, including McNary project was a loss of 2,344 aMW. There was some ability of the system to make up this lost generation at other plants.

5.8.2 Reservoir Elevations

The 60-year average annual reservoir elevations at Libby, Hungry Horse, Grand Coulee, and Dworshak were 732.3 m (2,402.5 ft); 1,073.2 m (3,521.1 ft); 385.7 m (1,265.5 ft); and 468.9 m (1,538.4 ft), respectively. Reservoirs drafted to their lowest point at the end the flood control evacuation period in March or April to elevations 716.6 m (2,351.0 ft); 1,064.4 m (3,492.2 ft); 377.7 m (1,234.7 ft); and 460.6 m (1,511.1 ft). They achieved their highest point at the end of the flood control refill period in July to elevations 745.0 m (2,444.2 ft); 1,082.6 m (3,551.8 ft); and 392.2 m (1,286.9 ft); with the exception of Dworshak, which peaked in June at elevation 481.6 m (1,579.9 ft).

When compared to Alternative A1, Libby drafted approximately 2.4 m (8 ft) deeper September through November to help replace generation lost from the drawdown of the Lower Snake River Project. Other periods were within 0.2 m (0.5 ft) of the elevations in Alternative A1. Hungry Horse drafted 0.5 m (1.5 ft) deeper September through December and from 0.3 m (1.0 ft) to 2.6 m (8.4 ft) deeper January through April. The reservoir elevations May through August drafted 0.1 m (0.3 ft) deeper. Grand Coulee, from September through April drafted approximately 0.3 m (1 ft) to 4.0 m (13 ft) deeper and varied less than 0.3 m (1.0 ft) during the other periods. Dworshak drafted 0.6 m (2 ft) deeper July through December and varied less than 0.3 m (1.0 ft) deeper the rest of the year. Deeper drafts are the result of projects attempting to replace generation lost due to drawdown.

5.8.3 Flows

In Alternative B1 the regulated flow at Lower Granite increases from 672.6 m^3/s (23,751 cfs) in September to a peak of 3,107 m^3/s (109,721 cfs) in May and decreases back down to 672.6 m^3/s (23,751 cfs) in September, with the exception of November where the regulated flow is 578.4 m^3/s (20,425 cfs). When compared to Alternative A1, the regulated flow at Lower Granite increased 23.4 m^3/s (827 cfs) in November and 15.3 m^3/s (539 cfs) in July. The regulated flows decreased 40.6 m^3/s (1,435 cfs) in the first part of April. Other periods changed less than 9.9 m^3/s (350 cfs).

At McNary, in Alternative B1, the regulated flows increased from 3,024.2 m^3/s (106,797 cfs) in September to a peak of 7,895.3 m^3/s (278,820) cfs in May and back down to the lowest flow in September, with the exception of January and March where the regulated flow was 5,528.2 m^3/s (195,228 ft) and 4,350.5 m^3/s (153,637 cfs), respectively. When compared to Alternative A1, the regulated flows increased 97.5 m^3/s (3,442 cfs) in the last part of August; 157.0 m^3/s (5,543 cfs) in September; 136.3 m^3/s (4,813 cfs) in October; 155.1 m^3/s (5,478 cfs) in November; 151.7 m^3/s (5,356 cfs) in January; 24.0 m^3/s (849 cfs) in June; and 45.8 m^3/s (1,616 cfs) in July. The regulated flows decreased 137.4 m^3/s (4,851 cfs) in December; 38.4 m^3/s (1,357 cfs) in February; 293.8 m^3/s (10,376 cfs) in March; 271.6 m^3/s (9,590 cfs) in the first part of April; 150.2 m^3/s (5,303 cfs) in the last part of April; and 26.1 m^3/s 921 cfs in May. Other periods changed less than 2.8 m^3/s (100 cfs).

The Salmon Biological Opinion regulated flow objective at Lower Granite in Alternative B1 was met in 27 years during the last part of April, in 41 years during May, in 39 years during June, in 23 years in July, in 4 years during the first part of August, and in no years during the last part of August.

In Alternative B1 at McNary, the Salmon Biological Opinion flow objectives were met in 40 years during the last part of April, in 57 years during May, in 34 years during June, in 5 years during July, in 1 year during the first part of August, and in no years during the last part of August.

5.9 Alternative B2 Impacts

5.9.1 System Generation

The average annual system generation for regulated hydroelectric plants in the model for Alternative B2 was 11,734 aMW. The highest period of system generation was during the peak load in January when the system generated 15,902 aMW. The periods of lowest system generation were in the first part of August at 9,621 aMW; the last part of August at 8,880 aMW; September at 8,062 aMW; and October at 8,706 aMW.

In this alternative, the Lower Snake River Project and John Day were drawn down to natural river level causing generation from these plants to be eliminated. Columbia River and Snake River flow augmentation was removed. The reduction in system generation is mainly due to these projects being drawn down to natural river. The McNary project was able to increase its average annual generation without the John Day project tailwater encroachment by 72 aMW. The net change in system generation, including McNary project was a loss of 2,344 aMW. Eliminating the Columbia River and Snake River flow augmentation allowed regulation of storage projects for power allowing the system to gain 87 aMW of annual generation, the difference between B1 and B2. There was some ability of the system to make up this lost generation at other plants.

5.9.2 Reservoir Elevations

The 60-year average annual reservoir elevations at Libby, Hungry Horse, Grand Coulee, and Dworshak were 734.0 m (2,408.3 ft); 1,075.2 m (3,527.6 ft); 386.2 m (1,267.1 ft); and 470.6 m (1,544.1 ft), respectively. Reservoirs drafted to their lowest point at the end of the flood control evacuation period in March or April to elevations 716.5 m (2,350.7 ft); 1,063.1 m (3,487.8 ft); 373.4 m (1,225.1 ft); and 449.4 m (1,474.3 ft). They achieved their highest point at the end of the flood control refill period in July to elevations 1,082.6 m (3,557.3 ft); 392.2 m (1,290.0 ft); and 485.3 m (1,598.5 ft) except for Libby which peaked in September to elevation 746.5 m (2,449.3 ft).

When compared to Alternative A1, Libby operated approximately 1.5 m (5.0 ft) to 6.1 m (20 ft) higher August through October. Other periods were within 0.5 m (1.5 ft) of the elevations in Alternative A1. Hungry Horse operated 1.4 m (4.5 ft) to 4.1 m (13.5 ft) higher June through December and approximately 0.9 m (3.0 ft) to 2.4 m (8.0 ft) deeper February through May. Grand Coulee operated 0.9 m (3.0 ft) to 2.1 m (7.0 ft) higher June through December and drafted approximately 0.9 m (3.0 ft) to 5.8 m (19 ft) deeper January through May. Dworshak had significant reservoir elevation differences compared to Alternative A1 due to the removal of Snake River flow augmentation. From December through April the project drafted between 4.3 m (14 ft) and 12.2 m (40 ft) deeper. From May through November the reservoir was 0.9 m (3.0 ft) to 18.9 m (62 ft) higher. The average annual reservoir elevation at Dworshak lowered by 1.4 m (4.5 ft). Deeper drafts are the result of other projects attempting to replace generation lost due to drawdown.

5.9.3 Flows

In Alternative B2 the regulated flow at Lower Granite increases from 747.6 m^3/s (26,403 cfs) in November to a peak of 2,972.6 m^3/s (104,978 cfs) in May and decreases back down to the lowest point of 609.7 m^3/s (21,530 cfs) in August, with the exception of September and October where the regulated flow is 877.7 m^3/s (30,995 cfs) and 822.4 m^3/s (29,043 cfs), respectively. When compared to Alternative A1, the regulated flow at Lower Granite increased between 89.7 m^3/s (3,167 cfs) and 216.5 m^3/s (7,646 cfs) from September to February. The regulated flows decreased between 32.3 m^3/s (1,142 cfs) and 467.8 m^3/s (16,521 cfs) from the first part of April to August. Other periods changed less than 4.2 m^3/s (150 cfs).

At McNary, in Alternative B2, the regulated flows increased from 2,978.5 m^3/s (105,184 cfs) in September to a peak of 7,723.6 m^3/s (272,758 cfs) in May and back down to the lowest flow in September, with the exception of January and February where the regulated flow was 5,935.9 m^3/s (209,626 cfs) and 5,482.5 m^3/s (193,612 cfs), respectively. When compared to Alternative A1, the regulated flows increased between 81.8 m^3/s (2,887 cfs) and 635.9 m^3/s (22,458 cfs) from September to March. The regulated flows decreased between 197.7 m^3/s (6,983 cfs) and 940.9 m^3/s (33,227 cfs) from the first part of April to the last part of August.

The Salmon Biological Opinion regulated flow objective at Lower Granite in Alternative B2 was met in 20 years during the last part of April, in 35 years during May, in 38 years during June, in 11 years in July, and in no years during the first or last part of August.

In Alternative B2 at McNary, the Salmon Biological Opinion flow objectives were met in 33 years during the last part of April, in 50 years during May, in 25 years during June, in 4 years during July, in 1 year during the first part of August, and in no years during the last part of August.

5.10 Alternative C1 Impacts

5.10.1 System Generation

The average annual system generation for regulated hydroelectric plants in the model for Alternative C1 was 12,206 aMW as shown in Table 5-1. The highest periods of system generation were in May and June which coincide with the spring runoff and the spring flow augmentation period. In these periods the system generated 15,430 aMW and 15,820 aMW, respectively. During the peak load period in January the system generated 15,311 aMW, which was nearly as high as the May and June generation. The periods of lowest system generation were in September at 8,866 aMW; October at 8,764 aMW; and November at 9,767 aMW.

In this alternative, the Lower Snake River Project was drawn down to natural river level, and John Day was operated at spillway level. Generation from the Snake River plants was eliminated and the generation at John Day was reduced substantially. The reduction in system generation is mainly due to the Snake River Project being drawn down to natural river level and John Day being operated at spillway level. John Day was able to generate when operated at spillway, but at a reduced level. The net generation lost when compared to Alternative A1 is 625 average annual MW, ranging from 969 aMW in May to 322 aMW in the last part of August. McNary project was able to increase its average annual generation without the John Day project tailwater encroachment by 72 aMW. The net change in system generation, including the McNary project, was a loss of 1,799 aMW. There was some ability of the system to make up this lost generation at other plants. Columbia River and Snake River flow augmentation remained unchanged.

5.10.2 Reservoir Elevations

The 60-year average annual reservoir elevations at Libby, Hungry Horse, Grand Coulee, and Dworshak were 732.5 m (2,403.1 ft); 1,073.3 m (3,521.4 ft); 385.9 m (1,266.2 ft); and 468.9 m (1,538.3 ft), respectively. Reservoirs drafted to their lowest point at the end of the flood control evacuation period in March or April to elevations 716.5 m (2,350.8 ft); 1,064.5 m (3,492.3 ft); 376.3 (1,234.7 ft); and 460.6 m (1,511.1 ft). They achieved their highest point at the end of the flood control refill period in July to elevations 745 m (2,444.2 ft), 1,082.6 m (3,551.8 ft), and 392.2 m (1,286.9 ft), with the exception of Dworshak, which peaked in June at elevation 481.5 m (1,579.8 ft).

When compared to Alternative A1, Libby drafted approximately 1.8 m (6.0 ft) deeper September through November to help replace generation lost from the drawdown of the Lower Snake River Project. Other periods were within 0.2 m (0.5 ft) of the elevations in Alternative A1. Hungry Horse drafted 0.5 m (1.5 ft) deeper September through December and from 0.3 m (1.0 ft) to 1.9 m (6.2 ft) deeper January through April. The reservoir elevations May through August were 0.2 m (0.5 ft) deeper. Grand Coulee, from October through April, drafted approximately 0.65 m (2.0 ft) to 3.7 m (12 ft) deeper and varied less than 0.3 m (1.0 foot) during the other periods. Dworshak drafted 0.6 m (2 ft) deeper July through December and varied less than 0.3 m (1.0 foot) deeper the rest of the year. Deeper drafts are the result of other projects attempting to replace generation lost due to drawdown.

5.10.3 Flows

In Alternative C1 the regulated flow at Lower Granite increases from 672.6 m^3/s (23,751 cfs) in September to a peak of 3,093.3 m^3/s (109,240 cfs) in May and decreases back down to 672.6 m^3/s (23,751 cfs) in September, with the exception of November when the regulated flow is 578.2 m^3/s (20,419

cfs). When compared to Alternative A1, the regulated flow at Lower Granite increased 23.2 m^3/s (821 cfs) in November, 22.1 m^3/s (779 cfs) in June, and 14.4 m^3/s (509 cfs) in July. The regulated flows decreased 40.6 m^3/s (1,435 cfs) in the first part of April and 20.7 m^3/s (732) in May. Other periods changed less than 9.9 m^3/s (350 cfs).

At McNary, in Alternative C1, the regulated flows increased from 2,962.1 m^3/s (104,606 cfs) in September to a peak of 7,884.4 m^3/s (278,435 cfs) in May and back down to the lowest flow in September, with the exception of January and February when the regulated flow was 5,533 m^3/s (195,397 cfs) and 4,872.3 m^3/s (172,063 cfs), respectively. When compared to Alternative A1, the regulated flows increased 94.2 m^3/s (3,327 cfs) in the last part of August; 94.9 m^3/s (3,352 cfs) in September; 80.3 m^3/s (2,836 cfs) in October; 137 m^3/s (4,838 cfs) in November; 156.5 m^3/s (5,525 cfs) in January; 25.7 m^3/s (909 cfs) in February; 34.5 m^3/s (1,218 cfs) in June; and 46.8 m^3/s (1,652 cfs) in July. The regulated flows decreased 107.6 m^3/s (3,801 cfs) in December; 250.5 m^3/s (8,845 cfs) in March; 275.6 m^3/s (9,734 cfs) in the first part of April; 145.9 m^3/s (5,151) in the last part of April; and 37 m^3/s (1,306 cfs) in May. Other periods changed less than 5.7 m^3/s (200 cfs).

The Salmon Biological Opinion regulated flow objective at Lower Granite in Alternative C1 was met in 27 years during the last part of April, in 40 years during May, in 41 years during June, in 22 years in July, in 4 years during the first part of August, and in no years during the last part of August.

In Alternative B1 at McNary, the Salmon Biological Opinion flow objectives were met in 40 years during the last part of April, in 57 years during May, in 33 years during June, in 5 years during July, in 1 year during the first part of August, and in no years during the last part of August.

5.11 Alternative C2 Impacts

5.11.1 System Generation

The average annual system generation for regulated hydroelectric plants in the model for Alternative B2 was 12,276 aMW as shown in Table 5-1. The highest period of system generation was during January and February when the system generated 16,506 aMW and 14,992 aMW. The periods of lowest system generation were in the last part of August at 9,348 aMW; September at 8,384 aMW; and October at 9,085 aMW.

In this alternative, the Lower Snake River Project was drawn down to natural river level, causing generation from these hydropower facilities to be eliminated, and John Day was operated at spillway level, causing its generation to be reduced. Columbia River and Snake River flow augmentation was removed. The reduction in system generation is mainly due to these projects being drawn down. John Day was able to generate when operated at spillway, but at a reduced level. The net generation lost when compared to Alternative A1 is 619 average annual MW, ranging from 1,000 aMW in May to 364 aMW in the last part of August. McNary project was able to increase its average annual generation without the John Day project tailwater encroachment by 73 aMW. The net change in system generation, including McNary project was a loss of 1,792 aMW. Eliminating the Columbia River and Snake River flow augmentation allowed regulation of storage projects for power allowing the system to gain 70 aMW of annual generation, the difference between C1 and C2. There was some ability of the system to make up this lost generation at other plants.

5.11.2 Reservoir Elevations

The 60-year average annual reservoir elevations at Libby, Hungry Horse, Grand Coulee, and Dworshak were 734 m (2,408.0 ft); 1074.8 m (3,526.3 ft); 385.7 m (1,265.3 ft); and 470.6 m (1,544.1 ft), respectively. Reservoirs drafted to their lowest point at the end the flood control evacuation period in March or April to elevations 716.5 m (2,350.8 ft); 1063 m (3,487.4 ft); 370.9 m (1,216.8 ft); and 449.3 m (1,474.2 ft). They achieved their highest point at the end of the flood control refill period in July to elevation 1083.8 m (3,555.8 ft); 393.2 m (1,290.0 ft); and 487.2 m (1,598.4 ft) except at Libby, which peaked in September to elevation 746.1 m (2,447.9 ft).

When compared to Alternative A1, Libby operated approximately 1.5 m (5.0 ft) to 5.5 m (18 ft) higher August through October. Other periods were within 0.5 m (1.5 ft) of the elevations in Alternative A1. Hungry Horse operated 0.7 m (2.2 ft) to 3.6 m (11.7 ft) higher June through January and approximately 1.3 m (4.4 ft) to 2.4 m (8.0 ft) deeper February through May. Grand Coulee operated 0.9 m (3.0 ft) to 2.1 m (7.0 ft) higher June through December and drafted approximately 0.9 m (3.0 ft) to 8.2 m (27 ft) deeper January through May. Dworshak had significant reservoir elevation differences compared to Alternative A1 due to the removal of Snake River flow augmentation. From December through April the project drafted between 4.3 m (14 ft) and 12.2 m (40 ft) deeper. From May through November the reservoir was 1.2 m (4.0 ft) to 18.9 m (62 ft) higher. The average annual reservoir elevation at Dworshak lowered by 1.4 m (4.5 ft). Deeper drafts are the result of other projects attempting to replace generation lost due to drawdown.

5.11.3 Flows

In Alternative C2, the regulated flow at Lower Granite increases from 746.9 m^3/s (26,375 cfs) in November to a peak of 2964.6 m^3/s (104,694 cfs) in May and decreases back down to the lowest point of 610.8 m^3/s (21,571 cfs) in August, with the exception of September and October where the regulated flow is 879.6 m^3/s (31,063 cfs) and 822.2 m^3/s (29,034 cfs), respectively. When compared to Alternative A1, the regulated flow at Lower Granite increased between 87.1 m^3/s (3,077 cfs) and 216.3 m^3/s (7,638 cfs) from September to February. The regulated flows decreased between 33.8 m^3/s (1,193 cfs) and 467.7 m^3/s (16,516 cfs) from the first part of April to the last part of August. Other periods changed less than 5.7 m^3/s (200 cfs).

At McNary, in Alternative C2, the regulated flows increased from 2966 m^3/s (104,743 cfs) in September to a peak of 7534.3 m^3/s (266,073 cfs) in May and back down to the lowest flow in September, with the exception of January and February when the regulated flow was 5888.6 m^3/s (207,954 cfs) and 5590 m^3/s (197,409 cfs), respectively. When compared to Alternative A1, the regulated flows increased between 73.4 m^3/s (2,591 cfs) and 743.5 m^3/s (26,255 cfs) from September to March. The regulated flows decreased between 262.8 m^3/s (9,279 cfs) and 900 m^3/s (31,783 cfs) from the first part of April to the last part of August.

The Salmon Biological Opinion regulated flow objective at Lower Granite in Alternative C2 was met in 20 years during the last part of April, in 35 years during May, in 39 years during June, in 11 years in July, in 4 years in the first part of August, and in no years during the last part of August.

In Alternative C2 at McNary, the Salmon Biological Opinion flow objectives were met in 33 years during the last part of April, in 47 years during May, in 25 years during June, in 4 years during July, in 1 year during the first part of August, and in no years during the last part of August.

Table 5-1. System Generation (aMW)

Alternative	AUG1	AUG 2	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR 1	APR 2	MAY	JUN	JUL	Ave Annual
A1	13196	10872	9466	9520	10414	14071	16800	15200	13820	14802	16890	18729	18834	13725	14038
A2	13200	10890	9467	9533	10418	14078	16803	15203	13820	14883	17129	19049	19139	13743	14108
A3	12230	10388	9046	8953	10021	12867	15987	14098	11794	12502	14372	16314	16703	12728	12771
A5	12078	9699	9317	9107	10494	13253	16230	14247	11796	12468	14054	16078	16538	12450	12805
A6a	13265	11167	9495	9535	10401	14083	16860	15127	13801	14809	17221	18544	18879	13816	14064
A6b	13237	10861	9412	9504	10437	14042	16840	15088	13819	14815	17346	18578	18755	13731	14028
B1	11519	9835	8703	8519	9377	11534	14535	12461	10337	11124	12830	14693	15114	11842	11647
B2	9621	8880	8062	8706	10658	12285	15902	14038	11387	11064	11619	14100	13794	11289	11734
C1	11898	10135	8866	8764	9767	12217	15311	13320	11045	11781	13499	15430	15820	12283	12206
C2	10047	9348	8384	9085	11059	12814	16506	14992	12243	11724	12148	14419	14467	11713	12276

Table 5-2. Difference in System Generation (aMW)

Alternative	AUG 1	AUG 2	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR 1	APR 2	MAY	JUN	JUL	Ave Annual
A1 - A2	(4)	(18)	(1)	(13)	(4)	(7)	(3)	(3)	0	(81)	(239)	(320)	(305)	(18)	(70)
A1 - A3	966	484	420	567	393	1204	813	1102	2026	2300	2518	2415	2131	997	1267
A1 - A5	1118	1173	149	413	(80)	818	570	953	2024	2334	2836	2651	2296	1275	1233
A1 - A6a	(69)	(295)	(29)	(15)	13	(12)	(60)	73	19	(7)	(331)	185	(45)	(91)	(26)
A1 - A6b	(41)	11	54	16	(23)	29	(40)	112	1	(13)	(456)	151	79	(6)	10
A1 - B1	1677	1037	763	1001	1037	2537	2265	2739	3483	3678	4060	4036	3720	1883	2391
A1 - B2	3575	1992	1404	814	(244)	1786	898	1162	2433	3738	5271	4629	5040	2436	2304
A1 - C1	1298	737	600	756	647	1854	1489	1880	2775	3021	3391	3299	3014	1442	1832
A1 - C2	3149	1524	1082	435	(645)	1257	294	208	1577	3078	4742	4310	4367	2012	1762

Table 5-3. Alternative A1 Generation at Lower Granite, Little Goose, Lower Monumental, and Ice Harbor (aMW)

Facility	AUG 1	AUG 2	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR 1	APR 2	MAY	JUN	JUL	Ave Annual
LWG	281	204	159	169	135	233	274	294	366	478	585	650	607	332	333
LGS	275	199	256	166	126	228	268	287	359	464	537	593	554	324	317
LMN	283	205	159	173	129	236	279	309	374	483	575	629	585	338	332
IHR	82	58	158	172	126	231	273	301	358	448	466	519	398	99	264
Total Generation	921	666	732	680	516	928	1094	1191	1457	1873	2163	2391	2144	1093	1246

Table 5-4. Libby, Hungry Horse, Grand Coulee and Dworshak Reservoir Elevations (ft)

Alternative	AUG 1	AUG 2	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR 1	APR 2	MAY	JUN	JUL	Ave Annual
LIB A1	2442.1	2440.0	2429.6	2428.3	2425.9	2411.0	2384.0	2360.6	2350.8	2352.0	2356.9	2398.2	2425.3	2444.2	2404.5
LIB A2	2442.0	2439.9	2429.5	2428.2	2425.9	2410.9	2383.9	2360.5	2350.7	2351.9	2356.8	2398.2	2425.1	2444.0	2404.4
LIB A3	2442.1	2440.0	2426.4	2423.9	2421.8	2411.0	2384.1	2360.6	2350.8	2352.0	2356.8	2398.2	2425.4	2444.2	2403.5
LIB A5	2441.5	2439.8	2428.1	2425.4	2422.5	2411.0	2384.0	2360.6	2350.8	2352.0	2356.8	2398.1	2425.4	2444.1	2403.8
LIB A6a	2441.6	2439.0	2428.8	2427.8	2425.5	2411.0	2384.0	2360.6	2350.8	2352.0	2356.9	2398.1	2425.3	2444.2	2404.3
LIB A6b	2441.9	2439.9	2429.2	2428.0	2425.6	2411.0	2384.0	2360.6	2350.8	2352.0	2356.9	2398.1	2425.3	2444.2	2404.3
LIB B1	2442.1	2440.0	2422.8	2419.5	2416.9	2411.0	2384.7	2360.8	2351.0	2352.1	2357.0	2398.2	2425.3	2444.2	2402.5
LIB B2	2447.8	2447.9	2449.3	2446.5	2426.8	2411.0	2384.0	2360.6	2350.7	2351.9	2356.0	2397.4	2426.1	2445.7	2408.3
LIB C1	2442.0	2440.0	2424.7	2422.3	2419.9	2411.0	2384.3	2360.7	2350.8	2352.0	2356.9	2398.1	2425.4	2444.2	2403.1
LIB C2	2447.8	2446.7	2447.9	2445.3	2426.4	2411.0	2384.0	2360.6	2350.8	2352.0	2356.1	2397.4	2426.1	2445.6	2408.0
HGH A1	3545.6	3540.4	3533.7	3528.4	3526.0	3517.1	3511.0	3503.0	3495.7	3496.0	3495.4	3527.4	3547.6	3552.2	3523.4
HGH A2	3545.6	3540.4	3533.5	3528.2	3525.7	3516.9	3510.9	3502.8	3495.5	3495.8	3495.3	3527.3	3547.6	3552.2	3523.3
HGH A3	3545.5	3540.4	3532.8	3527.5	3525.3	3516.3	3507.2	3497.8	3492.8	3494.3	3494.7	3527.0	3547.6	3552.1	3522.0
HGH A5	3543.9	3540.0	3533.4	3528.1	3525.9	3516.4	3508.1	3498.4	3493.4	3494.9	3495.2	3527.4	3547.2	3551.7	3522.3
HGH A6a	3544.3	3539.9	3532.5	3527.5	3525.3	3516.5	3510.4	3502.4	3495.0	3495.3	3494.8	3526.9	3547.1	3551.5	3522.7
HGH A6b	3544.9	3539.8	3532.8	3527.5	3525.2	3516.3	3510.0	3502.1	3494.8	3495.0	3494.5	3526.7	3546.9	3551.4	3522.6
HGH B1	3545.2	3540.1	3531.9	3526.7	3524.7	3516.1	3502.6	3496.0	3492.2	3494.1	3494.3	3526.9	3547.3	3551.8	3521.1
HGH B2	3555.5	3551.1	3546.8	3541.8	3539.6	3530.7	3512.6	3496.3	3488.1	3487.8	3489.2	3524.2	3552.1	3557.3	3527.6
HGH C1	3545.2	3540.1	3532.1	3526.9	3524.8	3516.1	3504.8	3496.8	3492.3	3494.2	3494.6	3526.9	3547.5	3551.8	3521.4
HGH C2	3553.7	3548.4	3544.0	3539.4	3537.5	3528.8	3513.2	3496.7	3487.4	3496.8	3487.8	3523.0	3551.1	3555.8	3526.3
GCL A1	1281.8	1280.4	1284.9	1286.9	1285.2	1279.9	1260.6	1249.1	1244.3	1242.6	1235.0	1253.3	1282.9	1286.9	1269.5
GCL A2	1281.8	1280.4	1284.9	1286.9	1285.2	1279.9	1260.6	1249.1	1244.3	1242.6	1235.0	1253.4	1282.9	1286.9	1269.5
GCL A3	1281.8	1280.4	1284.3	1285.8	1283.1	1277.4	1254.1	1240.1	1240.1	1240.2	1234.8	1253.3	1282.9	1286.9	1267.2
GCL A5	1280.9	1280.3	1284.8	1286.5	1284.8	1278.7	1254.9	1240.5	1240.3	1240.5	1234.5	1252.5	1282.8	1286.7	1267.5
GCL A6a	1280.3	1279.7	1284.8	1286.8	1285.1	1279.9	1259.8	1249.4	1244.4	1242.7	1232.2	1253.1	1281.9	1286.5	1269.1
GCL A6b	1281.6	1279.6	1284.8	1286.8	1285.1	1279.8	1259.7	1249.1	1244.3	1242.6	1232.2	1253.2	1282.8	1286.9	1269.2
GCL B1	1281.8	1280.4	1283.7	1284.2	1280.5	1273.6	1247.7	1236.0	1239.3	1240.0	1234.7	1253.2	1282.9	1286.9	1265.5
GCL B2	1289.1	1287.8	1288.0	1288.0	1287.9	1286.9	1257.7	1234.2	1225.1	1226.3	1226.6	1246.7	1286.0	1290.0	1267.1
GCL C1	1281.8	1280.4	1284.0	1284.7	1281.7	1275.7	1250.6	1237.4	1239.4	1240.1	1234.7	1253.2	1282.9	1286.9	1266.2
GCL C2	1288.9	1287.3	1288.0	1287.9	1287.7	1286.6	1258.2	1230.3	1216.8	1217.6	1218.0	1246.6	1286.0	1290.0	1265.3
DWR A1	1547.5	1533.1	1532.9	1534.6	1539.2	1542.4	1532.8	1519.4	1511.5	1518.6	1520.8	1559.3	1580.0	1563.6	1539.6
DWR A2	1547.5	1533.2	1532.9	1534.6	1539.2	1542.4	1532.8	1519.4	1511.5	1518.6	1520.8	1559.3	1580.0	1563.6	1539.6
DWR A3	1545.0	1530.9	1530.6	1532.3	1537.0	1540.3	1532.1	1518.9	1511.1	1518.3	1520.5	1559.5	1579.6	1561.0	1538.3
DWR A5	1591.4	1591.1	1558.8	1553.4	1517.7	1502.7	1474.9	1461.7	1461.6	1472.9	1493.2	1559.0	1590.9	1592.3	1528.9
DWR A6a	1542.7	1529.2	1528.9	1530.6	1535.4	1539.1	1531.5	1518.5	1510.5	1517.9	1524.0	1564.7	1591.3	1562.4	1539.2
DWR A6b	1532.5	1518.6	1518.3	1520.0	1524.9	1529.3	1522.7	1512.0	1505.3	1513.0	1515.3	1554.2	1576.6	1557.0	1530.0
DWR B1	1544.9	1530.9	1530.6	1532.3	1537.0	1540.3	1532.1	1518.9	1511.1	1518.3	1520.5	1559.8	1579.9	1561.4	1538.4
DWR B2	1596.0	1595.1	1577.4	1573.1	1554.3	1528.5	1499.9	1479.1	1474.3	1482.7	1499.5	1562.1	1595.6	1598.5	1544.1
DWR C1	1544.9	1530.9	1530.7	1532.3	1537.0	1540.3	1532.1	1518.9	1511.1	1518.3	1520.5	1559.0	1579.8	1561.4	1538.3
DWR C2	1595.9	1595.0	1577.0	1572.7	1554.0	1528.2	1500.1	1479.3	1474.2	1482.8	1499.6	1563.2	1595.9	1598.4	1544.1

Table 5-5. Difference in Libby, Hungry Horse, Grand Coulee and Dworshak Reservoir Elevations (ft)

Alternative	AUG 1	AUG 2	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR 1	APR 2	MAY	JUN	JUL	Ave Annual
LIB A1 - A2	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.2	0.2	0.1
LIB A1 - A3	0.0	0.0	3.2	4.4	4.1	0.0	(0.1)	0.0	0.0	0.0	0.1	0.0	(0.1)	0.0	1.0
LIB A1 - A5	0.6	0.2	1.5	2.9	3.4	0.0	0.0	0.0	0.0	0.0	0.1	0.1	(0.1)	0.1	0.7
LIB A1 - A6a	0.0	0.0	0.2	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.0	0.2	0.2	0.2	0.2
LIB A1 - A6b	0.2	0.1	0.4	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.2
LIB A1 - B1	0.0	0.0	6.8	8.8	9.0	0.0	(0.7)	(0.2)	(0.2)	(0.1)	(0.1)	0.0	0.0	0.0	2.0
LIB A1 - B2	(5.7)	(7.9)	(19.7)	(18.2)	(0.9)	0.0	0.0	0.0	0.1	0.1	0.9	0.8	(0.8)	(1.5)	(3.8)
LIB A1 - C1	0.1	0.0	4.9	6.0	6.0	0.0	(0.3)	(0.1)	0.0	0.0	0.0	0.1	(0.1)	0.0	1.4
LIB A1 - C2	(5.7)	(6.7)	(18.3)	(17.0)	(0.5)	0.0	0.0	0.0	0.0	0.0	0.8	0.8	(0.8)	(1.4)	(3.5)
HGH A1 - A2	0.0	0.0	0.2	0.2	0.3	0.2	0.1	0.2	0.2	0.2	0.1	0.1	0.0	0.0	0.1
HGH A1 - A3	0.1	0.0	0.9	0.9	0.7	0.8	3.8	5.2	2.9	1.7	0.7	0.4	0.0	0.1	1.4
HGH A1 - A5	1.7	0.4	0.3	0.3	0.1	0.7	2.9	4.6	2.3	1.1	0.2	0.0	0.4	0.5	1.1
HGH A1 - A6a	0.0	(0.1)	0.7	0.7	0.6	0.6	0.7	0.6	0.7	0.7	0.6	0.5	0.0	0.1	0.5
HGH A1 - A6b	0.7	0.6	0.9	0.9	0.8	0.8	1.0	0.9	0.9	1.0	0.9	0.7	0.7	0.8	0.8
HGH A1 - B1	0.4	0.3	1.8	1.7	1.3	1.0	8.4	7.0	3.5	1.9	1.1	0.5	0.3	0.4	2.3
HGH A1 - B2	(9.9)	(10.7)	(13.1)	(13.4)	(13.6)	(13.6)	(1.6)	6.7	7.6	8.2	6.2	3.2	(4.5)	(5.1)	(4.2)
HGH A1 - C1	0.4	0.3	1.6	1.5	1.2	1.0	6.2	6.2	3.4	1.8	0.8	0.5	0.1	0.4	2.0
HGH A1 - C2	(8.1)	(8.0)	(10.3)	(11.0)	(11.5)	(11.7)	(2.2)	6.3	8.3	(0.8)	7.6	4.4	(3.5)	(3.6)	(2.9)
GCL A1 - A2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	(0.1)	0.0	0.0	0.0
GCL A1 - A3	0.0	0.0	0.6	1.1	2.1	2.5	6.5	9.0	4.2	2.4	0.2	0.0	0.0	0.0	2.3
GCL A1 - A5	0.9	0.1	0.1	0.4	0.4	1.2	5.7	8.6	4.0	2.1	0.5	0.8	0.1	0.2	2.0
GCL A1 - A6a	(0.2)	0.4	0.0	0.0	0.0	0.0	0.8	(0.1)	0.0	0.0	2.8	(0.1)	0.8	0.5	0.3
GCL A1 - A6b	0.2	0.8	0.1	0.1	0.1	0.1	0.9	0.0	0.0	0.0	2.8	0.1	0.1	0.0	0.3
GCL A1 - B1	0.0	0.0	1.2	2.7	4.7	6.3	12.9	13.1	5.0	2.6	0.3	0.1	0.0	0.0	4.0
GCL A1 - B2	(7.3)	(7.4)	(3.1)	(1.1)	(2.7)	(7.0)	2.9	14.9	19.2	16.3	8.4	6.6	(3.1)	(3.1)	2.4
GCL A1 - C1	0.0	0.0	0.9	2.2	3.5	4.2	10.0	11.7	4.9	2.5	0.3	0.1	0.0	0.0	3.3
GCL A1 - C2	(7.1)	(6.9)	(3.1)	(1.0)	(2.5)	(6.7)	2.4	18.8	27.5	25.0	17.0	6.7	(3.1)	(3.1)	4.2
DWR A1 - A2	0.0	(0.1)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
DWR A1 - A3	2.5	2.2	2.3	2.3	2.2	2.1	0.7	0.5	0.4	0.3	0.3	(0.2)	0.4	2.6	1.3
DWR A1 - A5	(43.9)	(58.0)	(25.9)	(18.8)	21.5	39.7	57.9	57.7	49.9	45.7	27.6	0.3	(10.9)	(28.7)	10.7
DWR A1 - A6a	(3.8)	0.4	0.4	0.5	0.5	1.1	0.3	0.3	0.3	0.2	(3.8)	(11.8)	(16.3)	(6.0)	(2.9)
DWR A1 - A6b	15.0	14.5	14.6	14.6	14.3	13.1	10.1	7.4	6.2	5.6	5.5	5.1	3.4	6.6	9.6
DWR A1 - B1	2.6	2.2	2.3	2.3	2.2	2.1	0.7	0.5	0.4	0.3	0.3	(0.5)	0.1	2.2	1.2
DWR A1 - B2	(48.5)	(62.0)	(44.5)	(38.5)	(15.1)	13.9	32.9	40.3	37.2	35.9	21.3	(2.8)	(15.6)	(34.9)	(4.5)
DWR A1 - C1	2.6	2.2	2.2	2.3	2.2	2.1	0.7	0.5	0.4	0.3	0.3	0.3	0.2	2.2	1.3
DWR A1 - C2	(48.4)	(61.9)	(44.1)	(38.1)	(14.8)	14.2	32.7	40.1	37.3	35.8	21.2	(3.9)	(15.9)	(34.8)	(4.5)

Table 5-6. Lower Granite Regulated Flow (cfs)

Alternative	AUG 1	AUG 2	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR 1	APR 2	MAY	JUN	JUL	Ave Annual
Natural Flow	22,992	20,701	22,548	25,293	28,950	33,461	34,604	39,665	49,829	73,196	91,287	121,483	110,485	40,559	50,914
A1	41,418	30,212	23,751	25,197	19,598	32,417	38,072	40,780	51,071	71,829	96,549	109,972	101,397	48,838	50,925
A2	41,441	30,212	23,751	25,197	19,584	32,431	38,076	40,780	51,071	71,829	96,549	109,975	101,395	48,833	50,926
A3	41,268	29,987	23,751	25,197	20,371	32,327	37,735	40,737	51,065	70,394	96,557	109,799	101,647	49,375	50,926
A5	24,159	21,196	34,666	29,207	29,777	37,091	40,366	46,116	50,568	70,000	84,200	104,316	98,637	41,043	50,964
A6a	47,994	37,988	22,679	25,272	18,925	32,020	37,969	40,787	50,556	72,003	94,779	110,663	103,754	51,667	51,723
A6b	42,447	27,678	23,105	25,585	20,611	33,391	38,208	40,593	51,314	72,351	96,987	110,161	100,838	47,291	50,903
B1	41,435	29,984	23,751	25,197	20,425	32,274	37,735	40,737	51,065	70,394	96,557	109,721	101,644	49,377	50,926
B2	24,906	21,530	30,995	29,043	26,403	40,063	41,239	47,573	51,192	70,687	85,350	104,978	98,060	40,567	50,946
C1	41,463	29,946	23,751	25,197	20,419	32,281	37,735	40,739	51,065	70,394	96,557	109,240	102,176	49,347	50,928
C2	24,902	21,571	31,063	29,034	26,375	40,055	41,149	47,558	51,251	70,636	85,339	104,694	98,265	40,689	50,947

Table 5-7. McNary Regulated Flow (cfs)

Alternative	AUG 1	AUG 2	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR 1	APR 2	MAY	JUN	JUL	Ave Annual
Natural Flow	150,664	117,495	93,184	82,959	84,681	87,559	84,906	95,759	116,335	175,051	251,184	415,532	463,462	251,428	176,887
A1	170,177	132,419	101,254	103,051	103,443	147,979	189,872	171,154	164,013	188,382	239,090	279,741	274,515	180,160	173,352
A2	170,185	132,553	101,183	103,196	103,420	148,021	189,894	171,173	164,005	188,294	238,356	279,372	274,841	180,302	173,342
A3	169,610	135,372	103,006	104,597	106,972	145,522	194,060	173,406	157,766	179,508	234,076	279,002	275,364	181,782	173,397
A5	156,241	123,243	110,349	108,527	115,271	151,747	197,718	179,347	157,649	179,114	223,219	274,055	271,852	173,816	173,437
A6a	174,171	141,026	100,459	103,043	102,685	147,806	190,642	170,218	163,448	188,555	244,053	277,808	277,490	182,255	174,147
A6b	170,898	130,958	100,177	103,222	104,416	148,425	190,871	169,988	164,132	188,772	246,178	277,613	273,806	179,124	173,348
B1	170,140	135,861	106,797	107,864	108,921	143,128	195,228	169,797	153,637	178,792	233,787	278,820	275,364	181,776	173,386
B2	136,950	118,834	105,184	111,314	121,665	150,866	209,626	193,612	168,325	178,215	210,059	272,758	257,464	168,585	173,453
C1	170,004	135,746	104,606	105,887	108,281	144,178	195,397	172,063	155,168	178,648	233,939	278,435	275,733	181,812	173,395
C2	138,394	121,124	104,743	111,009	121,160	150,570	207,954	197,409	172,067	179,103	209,826	266,073	257,595	168,977	173,482

Table 5-8. Difference in Lower Granite Regulated Flow (cfs)

Alternative	AUG 1	AUG 2	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR 1	APR 2	MAY	JUN	JUL	Ave Annual
A1 - A2	(23)	0	0	0	14	(14)	(4)	0	0	0	0	(3)	2	5	(1)
A1 - A3	150	225	0	0	(773)	90	337	43	6	1,435	(8)	173	(250)	(537)	(1)
A1 - A5	17,259	9,016	(10,915)	(4,010)	(10,179)	(4,674)	(2,294)	(5,336)	503	1,829	12,349	5,656	2,760	7,795	(39)
A1 - A6a	(6,576)	(7,776)	1,072	(75)	673	397	103	(7)	515	(174)	1,770	(691)	(2,357)	(2,829)	(798)
A1 - A6b	(1,029)	2,534	646	(388)	(1,013)	(974)	(136)	187	(243)	(522)	(438)	(189)	559	1,547	22
A1 - B1	(17)	228	0	0	(827)	143	337	43	6	1,435	(8)	251	(247)	(539)	(1)
A1 - B2	16,512	8,682	(7,244)	(3,846)	(6,805)	(7,646)	(3,167)	(6,793)	(121)	1,142	11,199	4,994	3,337	8,271	(21)
A1 - C1	(45)	266	0	0	(821)	136	337	41	6	1,435	(8)	732	(779)	(509)	(3)
A1 - C2	16,516	8,641	(7,312)	(3,837)	(6,777)	(7,638)	(3,077)	(6,778)	(180)	1,193	11,210	5,278	3,132	8,149	(22)

Table 5-9. Difference in McNary Regulated Flow (cfs)

Alternative	AUG 1	AUG 2	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR 1	APR 2	MAY	JUN	JUL	Ave Annual
A1 - A2	(8)	(134)	71	(145)	23	(42)	-22	(19)	8	88	734	369	(326)	(142)	10
A1 - A3	567	(2,953)	(1,752)	(1,546)	(3,529)	2,457	(4,188)	(2,252)	6,247	8,874	5,014	739	(849)	(1,622)	(45)
A1 - A5	13,936	9,176	(9,095)	(5,476)	(11,828)	(3,768)	(7,846)	(8,193)	6,364	9,268	15,871	5,686	2,663	6,344	(85)
A1 - A6a	(3,994)	(8,607)	795	8	758	173	(770)	936	565	(173)	(4,963)	1,933	(2,975)	(2,095)	(795)
A1 - A6b	(721)	1,461	1,077	(171)	(973)	(446)	(999)	1,166	(119)	(390)	(7,088)	2,128	709	1,036	4
A1 - B1	37	(3,442)	(5,543)	(4,813)	(5,478)	4,851	(5,356)	1,357	10,376	9,590	5,303	921	(849)	(1,616)	(34)
A1 - B2	33,227	13,585	(3,930)	(8,263)	(18,222)	(2,887)	(19,754)	(22,458)	(4,312)	10,167	29,031	6,983	17,051	11,575	(101)
A1 - C1	173	(3,327)	(3,352)	(2,836)	(4,838)	3,801	(5,525)	(909)	8,845	9,734	5,151	1,306	(1,218)	(1,652)	(43)
A1 - C2	31,783	11,295	(3,489)	(7,958)	(17,717)	(2,591)	(18,082)	(26,255)	(8,054)	9,279	29,264	13,668	16,920	11,183	(130)

Table 5-10. Years Lower Granite Flow Objectives were Met (Number of Years Out of Sixty)

Alternative	AUG 1	AUG 2	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR 1	APR 2	MAY	JUN	JUL
Natural Flow	0	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	24	44	44	11
A1	4	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	27	39	39	18
A2	4	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	27	40	39	18
A3	4	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	27	41	41	21
A5	0	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	19	34	39	11
A6a	6	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	29	43	43	19
A6b	3	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	28	39	40	13
B1	4	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	27	41	39	23
B2	0	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	20	35	38	11
C1	4	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	27	40	41	22
C2	4	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	20	35	39	11

Note: See Section 4.2.4.2

Table 5-11. Years McNary Flow Objectives were Met (Number of Years Out of Sixty)

Alternative	AUG 1	AUG 2	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR 1	APR 2	MAY	JUN	JUL
Natural Flow	1	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	42	60	60	29
A1	1	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	40	57	28	5
A2	1	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	40	57	28	5
A3	1	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	40	57	35	5
A5	1	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	37	54	29	4
A6a	1	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	47	54	39	5
A6b	1	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	47	54	31	5
B1	1	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	40	57	34	5
B2	1	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	33	50	25	4
C1	1	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	40	57	33	5
C2	1	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	33	47	25	4

Note: See Section 4.2.4.1

6. Glossary

Acre-foot: The volume of water that will cover an area of one acre to a depth of one foot (326,000 gallons or 0.5 second foot days). It equals 1,233.5 m^3.

Actual Energy Capability (AEC): Each PNCA party's generating capability based on operating the coordinated system's reservoirs to the energy content curve or to proportional draft points.

Actual Energy Regulation (AER): Hydro regulation study used to determine each party's Actual Energy Capability.

Anadromous fish: Fish, such as salmon or steelhead trout, that hatch in fresh water, migrate to and mature in the ocean, and return to fresh water as adults to spawn.

Annual operating plan: A yearly plan for operating reservoirs on the Columbia River. Such a plan is specifically required by the Columbia River Treaty and by the Pacific Northwest Coordination Agreement.

Assured Operating Plan: A study mandated by the Columbia River Treaty that determines United States and Canadian benefits of Treaty projects.

Assured refill curve (ARC): A representation of the lowest drawdown level from which a reservoir could refill given a repetition of the third-lowest runoff year of record.

Average megawatt (aMW): The average amount of energy (in megawatts) supplied or demanded over a specified period of time; equivalent to the energy produced by the continuous operation of one megawatt of capacity over the specified period.

Baseload: In a demand sense, a load that varies only slightly in level over a specified time period. In a supply sense, a plant that operates most efficiently at a relatively constant level of generation.

Bypass system: Structure in a dam that provides a route for fish to move through or around the dam without going through the turbines.

Canadian Entitlement: Canada's share of hydropower generated at downstream projects by the use of the Columbia River Treaty projects.

Canadian Entitlement Allocation Agreements: Contracts that specify how much power is to be provided by five mid-Columbia projects as a result of increased flows made possible by the Columbia River Treaty projects.

Capacity: The maximum sustainable amount of power that can be produced by a generating resource at specified times under specified conditions or carried by a transmission facility; also, the maximum rate at which power can be saved by a nongenerating resource.

Capacity/energy exchange: A transaction in which one utility provides another with capacity service in exchange for additional amounts of firm energy (exchange energy) or money, under specified conditions, usually during off-peak hours.

Columbia River Treaty: U.S.-Canadian agreement for bilateral development and management of the Columbia River to achieve flood control and increased power production.

Columbia Storage Power Exchange (CSPE): A non-profit corporation of 11 Northwest utilities that issued revenue bonds to purchase the Canadian Entitlement and sell it to 41 Northwest utilities through a Bonneville Power Administration exchange agreement.

Composite Reservoir: A PNCA operational procedure that simplifies in-lieu energy transactions by treating federal upstream reservoirs as one reservoir located at Grand Coulee and assuming the same flow time between these upstream reservoirs and the mid-Columbia projects.

Content: An amount of water stored in a reservoir, usually expressed in terms of ksfd or MAF.

Coordinated operation: The operation of interconnected electrical systems to achieve greater reliability and economy; as applied to hydro resources, the operation of a group of hydro plants to obtain optimal power benefits.

Critical period: That portion of the historical 50-year streamflow record which, when combined with the drafting of all storage reservoirs from full to empty, would produce the least amount of energy shaped to seasonal load patterns.

Critical rule curves (CRC): A set of curves that define reservoir elevations that must be maintained to ensure that firm energy requirements can be met under the most adverse historical streamflow conditions. Critical rule curves are derived for all years in the critical period. They are used for proportional draft of reservoirs.

Critical water: Streamflows which occurred during the critical period.

Cubic feet per second (cfs): A unit of measurement pertaining to flow or discharge of water. One cfs is equal to 449 gallons per minute. A thousand cubic ft per second is abbreviated as kcfs.

Demand: The rate at which electric energy is used, whether at a given instant, or averaged over any designated period of time.

Discharge: Volume of water released from a dam or powerhouse at a given time, usually expressed in cubic ft per second.

Displacement: The substitution of less-expensive energy generation for more-expensive energy generation (usually hydroelectric energy transmitted from the Pacific Northwest or Canada is substituted for more expensive coal and oil-fired generation in California). Such displacement usually means that a thermal plant can reduce or shut down its production, saving money and often reducing air pollution.

Draft: Release of water from a storage reservoir.

Drawdown: The distance that the water surface of a reservoir is lowered from a given elevation as water is released from the reservoir. Also refers to the act of lowering reservoir levels. (Similar to draft.)

Elevation: Height in ft above sea level. Usually refers to reservoir forebay; used interchangeably with content because a forebay elevation implies a specific reservoir content. Tailwater level is also expressed as an elevation.

Energy: The ability to do work (i.e., exert a force over distance). Energy is measured in calories, joules, KWh, BTUs, MW-hours, and average MWs.

Energy content curves (ECC): A set of curves that establishes limits on the amount of reservoir drawdown permitted to produce energy in excess of FELCC.

FELCC: Firm energy load carrying capability (FELCC) is the amount of energy the region's generating system, or an individual utility or project, can be called on to produce on a firm basis during actual operations. FELCC is made up of both hydro and non-hydro resources, including power purchases.

Firm energy: The amount of energy that can be generated given the region's worst historical water conditions. It is energy produced on a guaranteed basis.

Fish ladders: A series of ascending pools constructed to enable salmon or other fish to swim upstream around or over a dam.

Fish passage facilities: Features of a dam that enable fish to move around, through, or over without harm. Generally an upstream fish ladder or a downstream bypass system.

Fixed drawdown period: The late summer and fall when the volume of the next spring runoff is not yet known, and reservoir operations are guided by fixed rule curves based on historical streamflow patterns.

Flood control rule curve: A curve, or family of curves, indicating the minimum reservoir drawdown required to control floods. (Also called Mandatory Rule Curve or Upper Rule Curve).

Flow: The volume of water passing a given point per unit of time. Same as streamflow.

Forced outage: An unforeseen outage that results from emergency conditions.

Forced outage reserves: Peak generating capability planned to be available to serve peak loads during forced outages of generating units.

Forebay: The portion of a reservoir at a hydroelectric plant that is immediately upstream of a dam or powerhouse.

Forebay elevation: Height of top of the forebay above sea level.

Freshet: A rapid temporary rise in streamflow caused by heavy rains or rapid snowmelt.

Generation: Act or process of producing electric energy from other forms of energy. Also refers to the amount of electric energy so produced.

Headwater benefits: Gains in usable downstream energy as a result of upstream storage.

Historical streamflow record: The unregulated streamflow data base of the 60 years beginning in July 1928; data are modified to adjust for factors such as irrigation depletions and evaporations for the particular operating year being studied.

Hydraulic Head: The vertical distance between the surface of the reservoir and the surface of the river immediately downstream from the powerhouse. Head is the difference between forebay and tailwater elevations.

Hydroelectricity: The production of electric power through use of the gravitational force of falling water.

Hydrology: The science dealing with the continuous cycle of evapotranspiration, precipitation, and runoff.

Hydrometeorological observations: Data that combine snowpack measurements and climatic forecasts to predict runoff.

Inflow (I) : Water that flows into a reservoir or forebay during a specified period.

In-lieu energy: Energy provided by a reservoir owner instead of water to which a downstream party is entitled.

Intake: The entrance to a conduit through a dam or water facility.

Interchange energy: Electric energy received by one utility system usually in exchange for energy to be delivered to another system at another time or place. Interchange energy is different from a direct purchase or sale, although accumulated energy balances are sometimes settled in cash.

Interruptible: A supply of power which, by agreement, can be shut off on relatively short notice (from minutes to a few days).

KAF (thousand acre-feet): This is .504 thousand second foot days.

kcfs: A measurement of water flow equivalent to 1,000 cubic feet of water passing a given point for an entire second.

ksfd: A volume of water equal to 1,000 cubic feet of water flowing past a point for an entire day. Same as 1.98 KAF.

Levee: An embankment constructed to prevent a river from overflowing.

Load: The amount of electric power or energy delivered or required at any specified point or points on a system. Load originates primarily at the energy-consuming equipment of customers.

Lock: A chambered structure on a waterway closed off with gates for the purpose of raising or lowering the water level within the lock chamber so ships can move from one elevation to another along the waterway.

MAF (million acre-feet): This is equivalent to the volume of water that will cover an area of one million acres to a depth of one foot. One MAF equals 1,000 KAF.

Mainstem: The principal river in a basin, as opposed to the tributary streams and smaller rivers that feed into it.

Megawatt (MW): A megawatt is one million watts, a measure of electrical power or generating capacity. A megawatt will typically serve about 1,000 people. The Dalles Dam produces an average of about 1,000 megawatts.

Megawatt-hour (MWh): A unit of electrical energy equal to one megawatt of power applied for one hour.

Mid-Columbia: The section of the Columbia River from Grand Coulee Dam to its junction with the Snake River.

Nitrogen supersaturation: A condition of water in which the concentration of dissolved nitrogen exceeds the saturation level of water. Excess nitrogen can harm the circulatory systems of fish.

Nonfirm energy: Energy in excess of firm energy, which is available when water conditions are better than those in the critical period; generally such energy is sold on an interruptible (nonguaranteed) basis. Also called secondary energy.

Non-power operating requirements: Operating requirements at hydroelectric projects that pertain to navigation, flood control, fish and wildlife, recreation, irrigation, and other non-power uses of the river.

Northwest Power Pool Coordinating Group: An operating group made up of BPA, the Corps, BOR, and public and private generating utilities in the Northwest. One of the group's functions is administering the Pacific Northwest Coordination Agreement.

Off-peak hours: Period of relatively low demand for electrical energy, as specified by the supplier (such as the middle of the night).

Operating limits: Also called operating requirements or constraints. Limits or requirements that must be factored into the planning process for operating reservoirs and generating projects. (Also see non-power operating requirements and operating requirements).

Operating procedure: Alternative method substituted for a provision in the PNCA contract by agreement of parties, clarification of the contract, or method for carrying out a procedure.

Operating requirements: Guidelines and limits that must be followed in the operation of a reservoir or generating project. These requirements may originate from authorizing legislation, physical plant limitations, environmental impact analysis, or input from government agencies and other entities representing specific river uses. Operating requirements are submitted annually to the Northwest Power Pool by project owners for planning purposes.

Operating rule curve: A composite curve, derived from a family of curves, indicating how a reservoir is to be operated under specific conditions. The operating rule curve accounts for multiple operating objectives, including flood control, hydropower generation, releases for fish migration, and refill.

Operating year: The 12-month period from August 1 through July 31.

Outage: In a power system, the state of a component (such as a generating unit, transmission line, etc.) when it is not available to perform its function due to some event directly associated with the component.

Outflow (O): The water that is released from a project during a specified period.

Pacific Northwest Coordination Agreement (PNCA): A binding agreement among BPA, the Corps, BOR, and the major hydro generating utilities in the Pacific Northwest that stemmed from the Columbia River Treaty. The Agreement specifies a multitude of operating rules, criteria, and procedures for coordinating operation of the Pacific Northwest hydropower system for power production. It directs operation of major generating facilities as though they belonged to a single owner.

Peak load: The maximum electrical demand in a stated period of time. It may be the maximum instantaneous load or the maximum average load within a designated period of time.

Project: Run-of-river or storage dam and related facilities; also a diversion facility.

Project outflow: The volume of water per unit of time released from a project. Same as discharge and outflow.

Proportional draft: A condition in which all reservoirs are drafted among rule curves in the same proportion to meet firm loads.

Proportional draft point (PDP): Reservoir elevation that guides operations whenever drafting to the ECC will not produce FELCC; all reservoirs' PDPs are the same proportional distance between the critical rule curves unless restricted by NPRs.

Provisional energy: Energy produced by drafting below the ECC or PDP and delivered under contracts which provide for the return of the energy to the delivering utility under certain conditions. Provisional energy is called Advance Energy in contracts between BPA and its direct service industrial customers.

Refill: The point at which the hydro system is considered "full" from the seasonal snowmelt runoff. Also, refers to the annual process of filling a reservoir.

Reliability: For a power system, a measure of the degree of certainty that the system will continue to meet load for a specified period of time.

Reregulation: Storing erratic discharges of water from an upstream hydroelectric plant and releasing them uniformly from a downstream storage plant.

Reregulating reservoir: A reservoir located downstream from a hydroelectric peaking plant having sufficient pondage to store the widely fluctuating discharges from the peaking plant and release them in a relatively uniform manner downstream.

Reservoir content: See content and reservoir storage.

Reservoir draft rate: The rate at which water, released from storage behind a dam, reduces the elevation of the reservoir.

Reservoir elevation: The height above sea level of the water stored behind a dam. Same as forebay elevation.

Reservoir storage: The volume of water in a reservoir at a given time. Same as reservoir content. Reservoir storage implies a reservoir elevation. Tables are used to convert content to elevation at each - reservoir.

Resident fish: Fish species that reside in fresh water throughout their lives.

Restoration: Adjustments that permit all PNCA projects to carry the same firm energy load with as without Canadian Treaty storage; projects losing load-carrying capability are restored by projects gaining capability.

Rule curves: Water levels, represented graphically as curves, that guide reservoir operations. See critical rule curves, energy content curves, and flood control rule curves.

Run-of-river dams: Hydroelectric generating plants that operate based only on available inflow and a limited amount of short-term storage (daily/weekly pondage).

Secondary energy: Hydroelectric energy in excess of firm energy, often used to displace thermal resources. Sometimes called nonfirm energy.

Secretary's Principles: The framework of rights and obligations that forms the basis of PNCA.

Shaping: The scheduling and operation of generating resources to meet seasonal and hourly load variations. Load shaping on a hydro system usually involves the adjustment of reservoir releases so that generation and load are continuously in balance.

Shifting: In planning, moving surplus or deficit FELCC from one year of the critical period to another to increase the FELCC's value.

Smolt: A juvenile salmon or steelhead migrating to the ocean and undergoing physiological changes to adapt its body from a freshwater to a saltwater environment.

Spawning: The releasing and fertilizing of eggs by fish.

Spill: Water passed over a spillway without going through turbines to produce electricity. Spill can be forced, when there is no storage capability and flows exceed turbine capacity, or planned, for example, when water is spilled to enhance juvenile fish survival.

Spillway: Overflow structure of a dam.

Storage energy: The energy equivalent of water stored in a reservoir above normal bottom elevation.

Storage reservoirs: Reservoirs that have space for retaining water from springtime snowmelts. Careful scheduling of reservoir refill serves to prevent floods in high runoff years. Retained water is released as necessary for multiple uses - power production, fish passage, irrigation, and navigation.

Streamflow: The rate at which water passes a given point in a stream, usually expressed in cubic ft per second (cfs).

Surplus: Energy generated that is beyond the immediate needs of the producing system. This energy may be sold on an interruptible basis or as nonfirm power.

Tailwater: Water immediately below the power plant. Tailwater elevation refers to the level of that water.

Thermal power plant: Generating plant that converts heat energy into electrical energy. Coal, oil, and gas-fired power plants and nuclear power plants are common thermal resources.

Thermal Resource: Electrical generating means that rely on conventional fuels such as coal, oil, and gas.

Transmission: Transporting electric energy in bulk from one point to another in the power system rather than to individual customers.

Transmission grid: An inter-connected system of electric transmission lines and associated equipment for transferring electric energy in bulk.

Turbine: Machinery that converts kinetic energy of a moving fluid, such as falling water or steam, to mechanical power. Turbines are used to turn generators that convert mechanical energy to electricity.

Usable storage: Water occupying active storage capacity of a reservoir.

Usable storage capacity: The portion of the reservoir storage capacity in which water normally is stored, or from which water is withdrawn for beneficial uses, in compliance with operating agreements.

Variable energy content curve (VECC): The January through July portion of the energy content curve. The VECC is based on the expected amount of spring runoff.

Water Budget: A volume of water to be reserved and released in the spring if needed to assist in the downstream migration of juvenile salmon and steelhead.

Water Rights: Priority claims to water. In western States, water rights are based on the principle "first in time, first in right," meaning older claims take precedence over newer ones.

Watt: A measure of the rate at which energy is produced, exchanged, or consumed.

Wheeling: Using transmission facilities of one system to transmit power of and for another system.

Annex A

Comparison Tables

Table A-1. Comparison of Key Data for Alternative A1 and Alternative A2

Key Data	**Alternative A1**	**Alternative A2**	**Difference A1 – A2**
Brownlee Reservoir			
July Average EOM Elev. – ft	2,069.0	2,069.0	0
July's did not refill – No.	60	60	0
Average Pool Elev. - ft	2,059.3	2,059.3	0
Dworshak Reservoir			
July Average EOM Elev. – ft	1,563.6	1,563.6	0
July's did not refill – No.	42	41	1
Average Pool Elev. - ft	1,539.6	1,539.6	0
Lower Granite			
Apr 2- Jun 60-year Average Regulated Flow – cfs	103,937	103.938	-1
Jul – Aug 2 60-year Average Regulated Flow – cfs	42,236	42,239	-3
McNary Project			
Apr 2- Jun 60-year Average Regulated Flow – cfs	269,654	269,488	166
Jul – Aug 2 60-year Average Regulated Flow – cfs	165,424	165,532	108
Average System Generation	14,038	14,108	-70

Table A-2. Comparison of Key Data for Alternative A1 and Alternative A3

Key Data	**Alternative A1**	**Alternative A3**	**Difference A1 – A3**
Brownlee Reservoir			
July Average EOM Elev. – ft	2,069.0	2,069.0	0
July's did not refill – No.	60	60	0
Average Pool Elev. - ft	2,059.3	2,059.3	0
Dworshak Reservoir			
July Average EOM Elev. – ft	1,563.6	1,561.0	2.6
July's did not refill – No.	42	46	-4
Average Pool Elev. - ft	1,539.6	1,538.3	1.3
Lower Granite			
Apr 2- Jun 60-year Average Regulated Flow – cfs	103,937	103,967	-30
Jul – Aug 2 60-year Average Regulated Flow – cfs	42,236	42,410	-174
McNary Project			
Apr 2- Jun 60-year Average Regulated Flow – cfs	269,654	268,698	956
Jul – Aug 2 60-year Average Regulated Flow – cfs	165,424	166,860	-1,436
Average System Generation	14,038	12,771	-1,267

Table A-3. Comparison of Key Data for Alternative A1 and Alternative A5

Key Data	**Alternative A1**	**Alternative A5**	**Difference A1 – A5**
Brownlee Reservoir			
July Average EOM Elev. – ft	2,069.0	2,072.0	-3
July's did not refill – No.	60	46	14
Average Pool Elev. - ft	2,059.3	2,060.3	1.0
Dworshak Reservoir			
July Average EOM Elev. – ft	1,563.6	1,592.3	-28.70
July's did not refill – No.	42	42	0
Average Pool Elev. - ft	1,539.6	1,528.7	10.7
Lower Granite			
Apr 2- Jun 60-year Average Regulated Flow – cfs	103,937	98,104	5,833
Jul – Aug 2 60-year Average Regulated Flow – cfs	42,236	37,681	4,555
McNary Project			
Apr 2- Jun 60-year Average Regulated Flow – cfs	269,654	263,151	6,503
Jul – Aug 2 60-year Average Regulated Flow – cfs	165,424	156,512	8,912
Average System Generation	14,038	12,805	1,233

Table A-4. Comparison of Key Data for Alternative A1 and Alternative A6a

Key Data	**Alternative A1**	**Alternative A6a**	**Difference A1 – A6a**
Brownlee Reservoir			
July Average EOM Elev. – ft	2,069.0	2,069.0	0
July's did not refill – No.	60	60	0
Average Pool Elev. – ft	2,059.3	2,058.2	1.10
Dworshak Reservoir			
July Average EOM Elev. – ft	1,563.6	1,569.6	-6
July's did not refill – No.	42	47	-5
Average Pool Elev. – ft	1,539.6	1,542.5	-2.90
Lower Granite			
Apr 2- Jun 60-year Average Regulated Flow – cfs	103,937	104,800	-863
Jul – Aug 2 60-year Average Regulated Flow – cfs	42,236	47,248	-5012
McNary Project			
Apr 2- Jun 60-year Average Regulated Flow – cfs	269,654	271,020	-1,366
Jul – Aug 2 60-year Average Regulated Flow – cfs	165,424	169,659	-4,235
Average System Generation	14,038	14,064	-26

Table A-5. Comparison of Key Data for Alternative A1 and Alternative A6b

Key Data	**Alternative A1**	**Alternative A6B**	**Difference A1 – A6b**
Brownlee Reservoir			
July Average EOM Elev. – ft	2,069.0	2,069.0	0
July's did not refill – No.	60	60	0
Average Pool Elev. – ft	2,059.3	2,058.2	1.10
Dworshak Reservoir			
July Average EOM Elev. – ft	1,563.6	1,569.6	-6
July's did not refill – No.	42	47	-5
Average Pool Elev. – ft	1,539.6	1,542.5	-2.90
Lower Granite			
Apr 2- Jun 60-year Average Regulated Flow – cfs	103,937	104,800	-863
Jul – Aug 2 60-year Average Regulated Flow – cfs	42,236	47,248	-5,012
McNary Project			
Apr 2- Jun 60-year Average Regulated Flow – cfs	269,654	271,020	-1,366
Jul – Aug 2 60-year Average Regulated Flow – cfs	165,424	169,659	-4,235
Average System Generation	14,038	14,028	10

Table A-6. Comparison of Key Data for Alternative A1 and Alternative B1

Key Data	**Alternative A1**	**Alternative B1**	**Difference A1 – B1**
Brownlee Reservoir			
July Average EOM Elev. – ft	2,069.0	2,069.0	0
July's did not refill – No.	60	60	0
Average Pool Elev. - ft	2,059.3	2,059.3	0
Dworshak Reservoir			
July Average EOM Elev. – ft	1,563.6	1,561.4	2.2
July's did not refill – No.	42	46	-4
Average Pool Elev. - ft	1,539.6	1,538.4	1.2
Lower Granite			
Apr 2- Jun 60-year Average Regulated Flow – cfs	103,937	103,934	3
Jul – Aug 2 60-year Average Regulated Flow – cfs	42,236	42,450	-214
McNary Project			
Apr 2- Jun 60-year Average Regulated Flow – cfs	269,654	268,067	1,387
Jul – Aug 2 60-year Average Regulated Flow – cfs	165,424	167,111	-1,687
Average System Generation	14,038	11,647	2,391

Table A-7. Comparison of Key Data for Alternative A1 and Alternative B2

Key Data	**Alternative A1**	**Alternative B2**	**Difference A1 – B2**
Brownlee Reservoir			
July Average EOM Elev. – ft	2,069.0	2,072.0	-3.0
July's did not refill – No.	60	46	14
Average Pool Elev. – ft	2,059.3	2,060.3	-1.0
Dworshak Reservoir			
July Average EOM Elev. – ft	1,563.6	1,598.5	-34.90
July's did not refill – No.	42	13	29
Average Pool Elev. – ft	1,539.6	1,544.1	-4.50
Lower Granite			
Apr 2- Jun 60-year Average Regulated Flow – cfs	103,937	98,373	5,564
Jul – Aug 2 60-year Average Regulated Flow – cfs	42,236	31,865	10,371
McNary Project			
Apr 2- Jun 60-year Average Regulated Flow – cfs	269,654	254,346	15,308
Jul – Aug 2 60-year Average Regulated Flow – cfs	165,424	148,092	17,332
Average System Generation	14,038	11,734	2,304

Table A-8. Comparison of Key Data for Alternative A1 and Alternative C1

Key Data	**Alternative A1**	**Alternative C1**	**Difference A1 – C1**
Brownlee Reservoir			
July Average EOM Elev. – ft	2,069.0	2,069.0	0
July's did not refill – No.	60	60	0
Average Pool Elev. - ft	2,059.3	2,059.5	-0.2
Dworshak Reservoir			
July Average EOM Elev. – ft	1,563.6	1,561.4	2.2
July's did not refill – No.	42	46	-4
Average Pool Elev. - ft	1,539.6	1,538.3	1.3
Lower Granite			
Apr 2- Jun 60-year Average Regulated Flow – cfs	103,937	103,948	11
Jul – Aug 2 60-year Average Regulated Flow – cfs	42,236	42,432	-196
McNary Project			
Apr 2- Jun 60-year Average Regulated Flow – cfs	269,654	268,586	1,068
Jul – Aug 2 60-year Average Regulated Flow – cfs	165,424	167,067	-1,643
Average System Generation	14,038	12,206	1,832

Table A-9 Comparison of Key Data for Alternative A1 and Alternative C2

Key Data	**Alternative A1**	**Alternative C2**	**Difference A1 – C2**
Brownlee Reservoir			
July Average EOM Elev. – ft	2,069.0	2,072.0	-3
July's did not refill – No.	60	46	14
Average Pool Elev. - ft	2,059.3	2,060.3	-1.0
Dworshak Reservoir			
July Average EOM Elev. – ft	1,563.6	1,595.9	-32.30
July's did not refill – No.	42	48	-6
Average Pool Elev. - ft	1,539.6	1,544.1	-4.5
Lower Granite			
Apr 2- Jun 60-year Average Regulated Flow – cfs	103,937	98,336	5,601
Jul – Aug 2 60-year Average Regulated Flow – cfs	42,236	31,935	10,301
McNary Project			
Apr 2- Jun 60-year Average Regulated Flow – cfs	269,654	251,625	18,029
Jul – Aug 2 60-year Average Regulated Flow – cfs	165,424	149,228	15,196
Average System Generation	14,038	12,276	1,762

This page is intentionally left blank.

Annex B

Comparison Graphs

Comparison Graphs

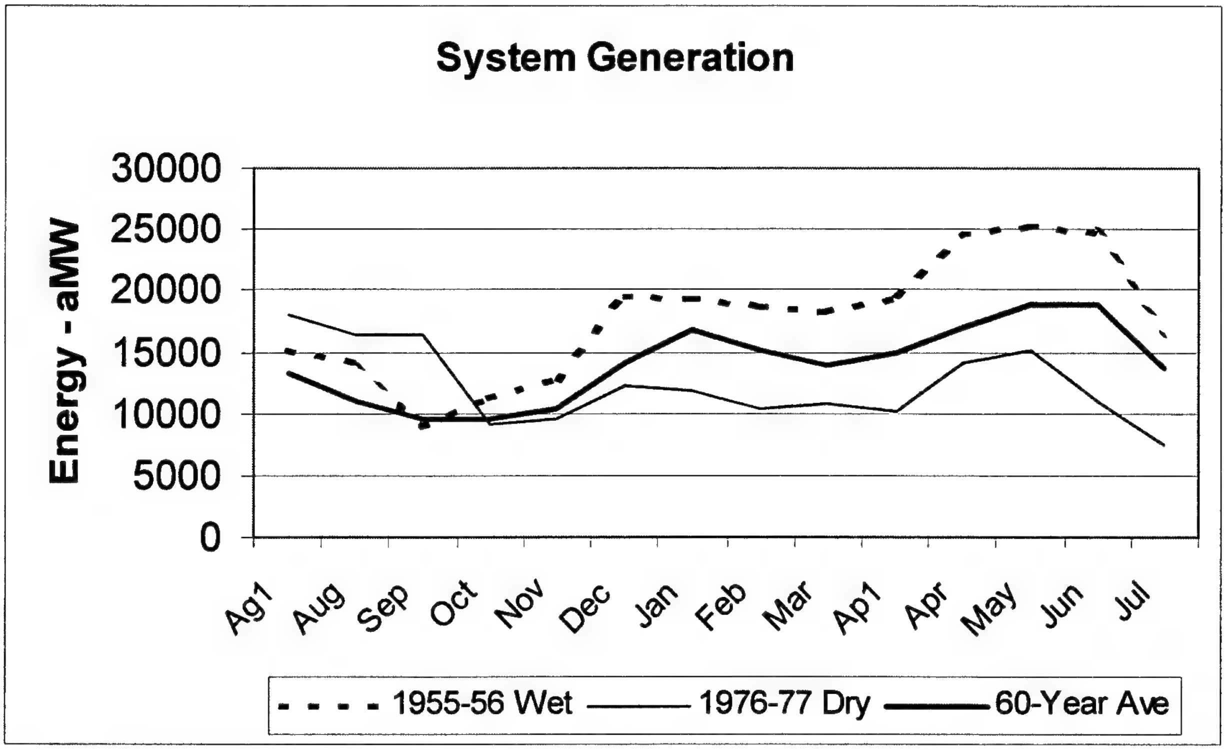
Hydroregulation data was graphed for each alternative at various points in the Columbia River Reservoir System. At Dworshak, the end-of-month elevation and regulated outflow was presented. A graph of the regulated outflow was provided for The Dalles, McNary, and Lower Granite. These graphs show a representative wet year that used 1955-56 water conditions, a representative dry year that used 1976-77 water conditions, and the 60-year average.

In order to show how each alternative impacted refill, a graph of probability of July refill was presented for Dworshak. The end of July data for the 60-year period of record was used to show the percent of time a given reservoir elevation was equaled or exceeded. For example, Figure B-1 shows Dworshak end of July reservoir elevation of 1,584 ft being equaled or exceeded 40 percent of the time.

During the spring anadromous migration season, the flows from April 16 through June 30 were averaged and used to develop a flow duration curve. Both Dworshak and Lower Granite were displayed. This graph can be used to determined the percent of time a given flow objective was equaled or exceeded. For example, Figure B-1 shows Dworshak regulated outflow of 8,987 cfs was equaled or exceeded 40 percent of the time.

The summer anadromous migration season flows from July 1 through August 31 were averaged and used to develop a flow duration curve. Both Dworshak and Lower Granite were displayed. This graph can be used to determined the percent of time a given flow objective was equaled or exceeded. For example, Figure B-1 shows Dworshak regulated outflow of 9,334 cfs was equaled or exceeded 40 percent of the time.

Figure B-1. Alternative A1 Graphs



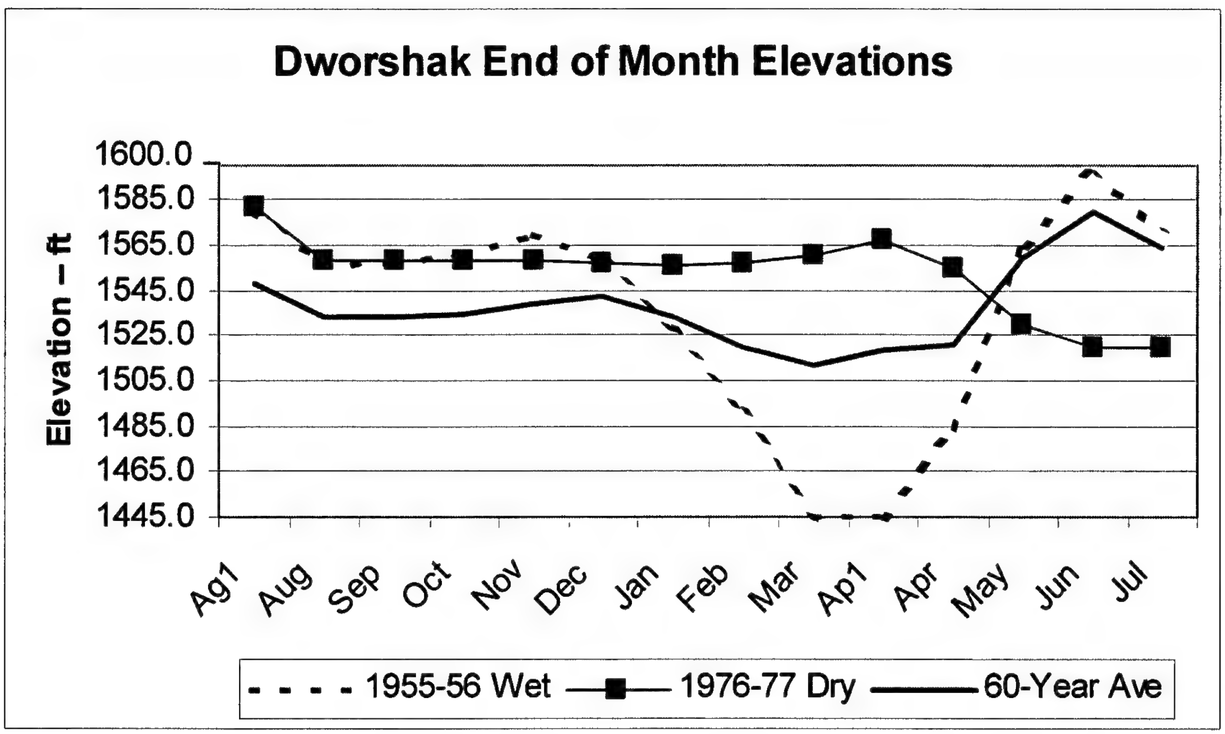
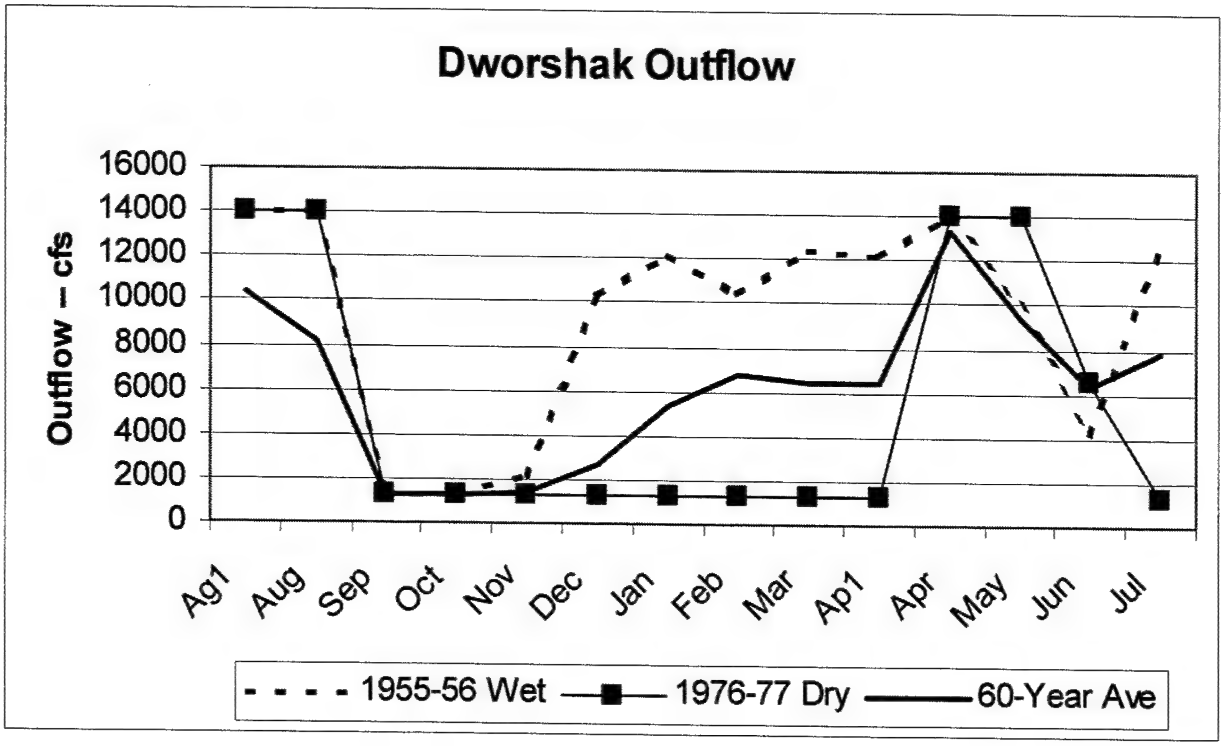


Figure B-1. Alternative A1 Graphs (continued)



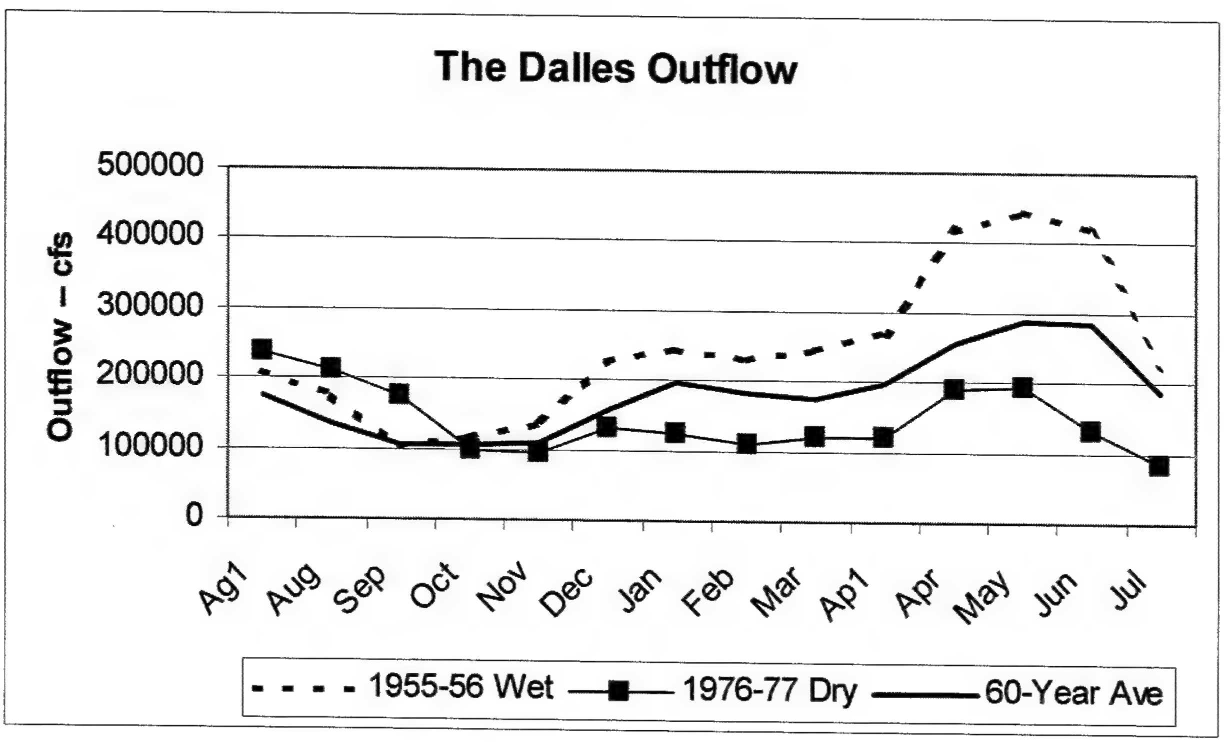
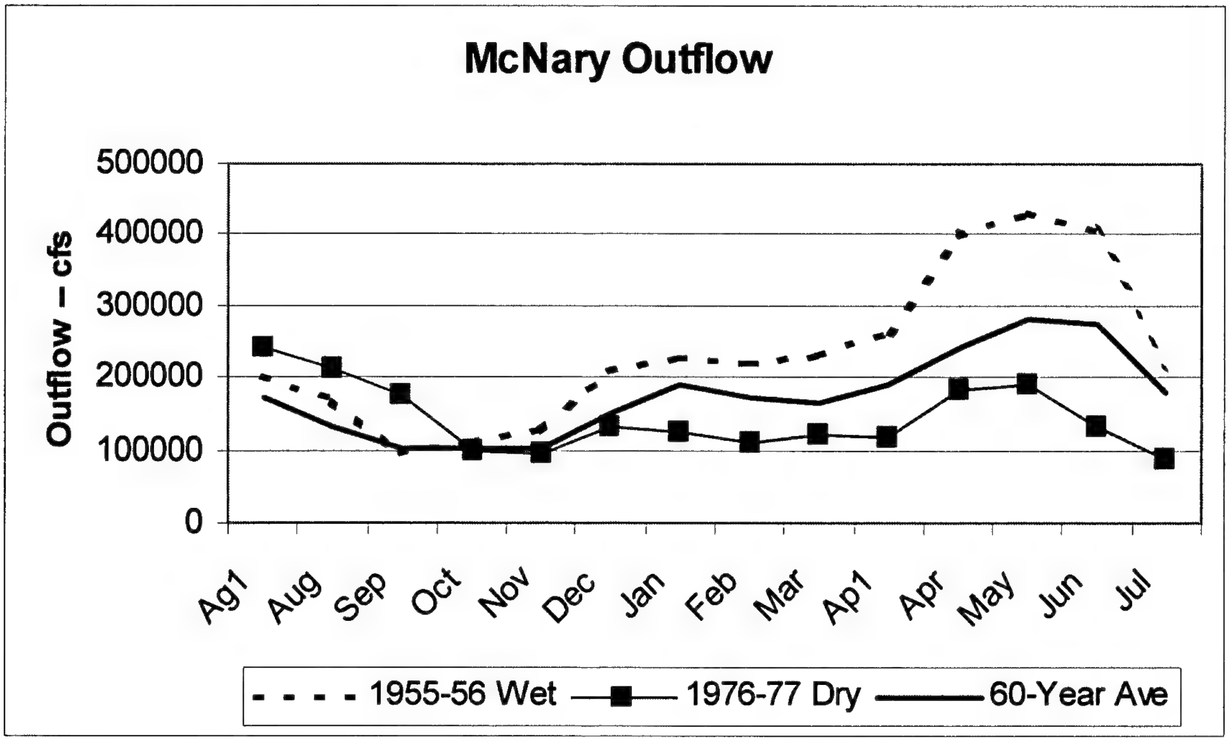


Figure B-1. Alternative A1 Graphs (continued)



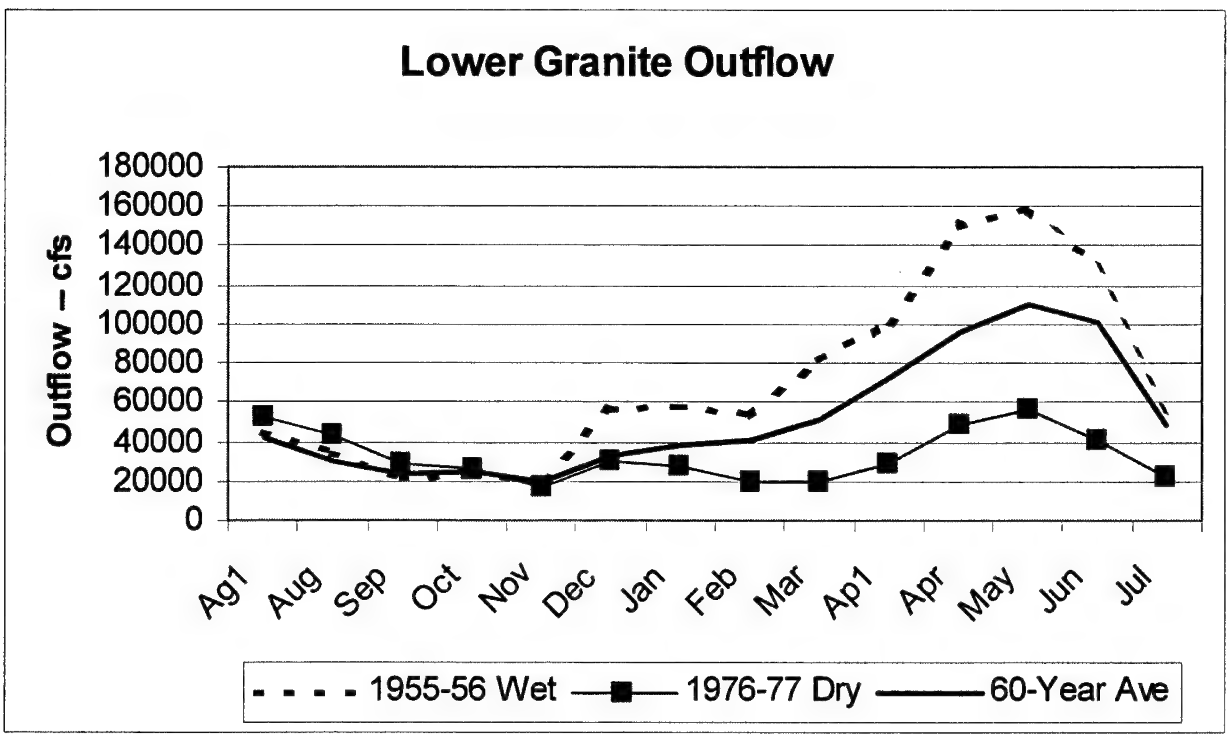
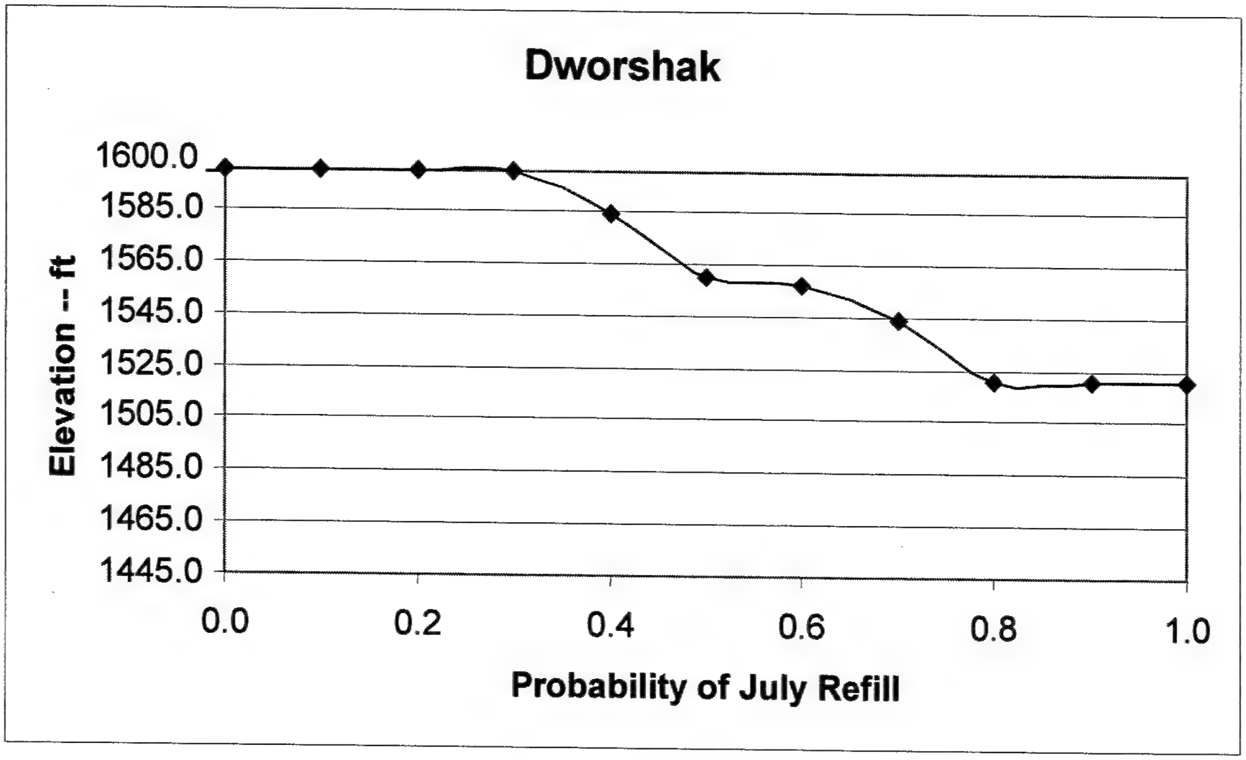


Figure B-1. Alternative A1 Graphs (continued)



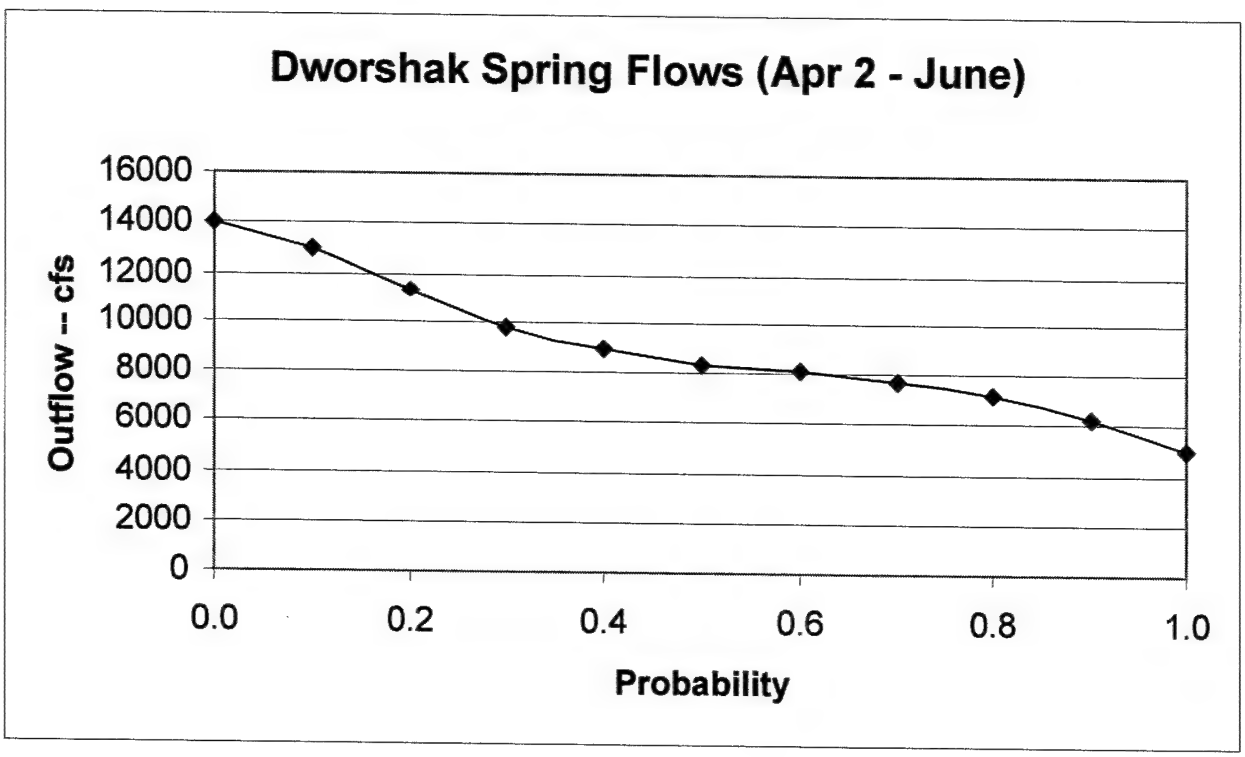
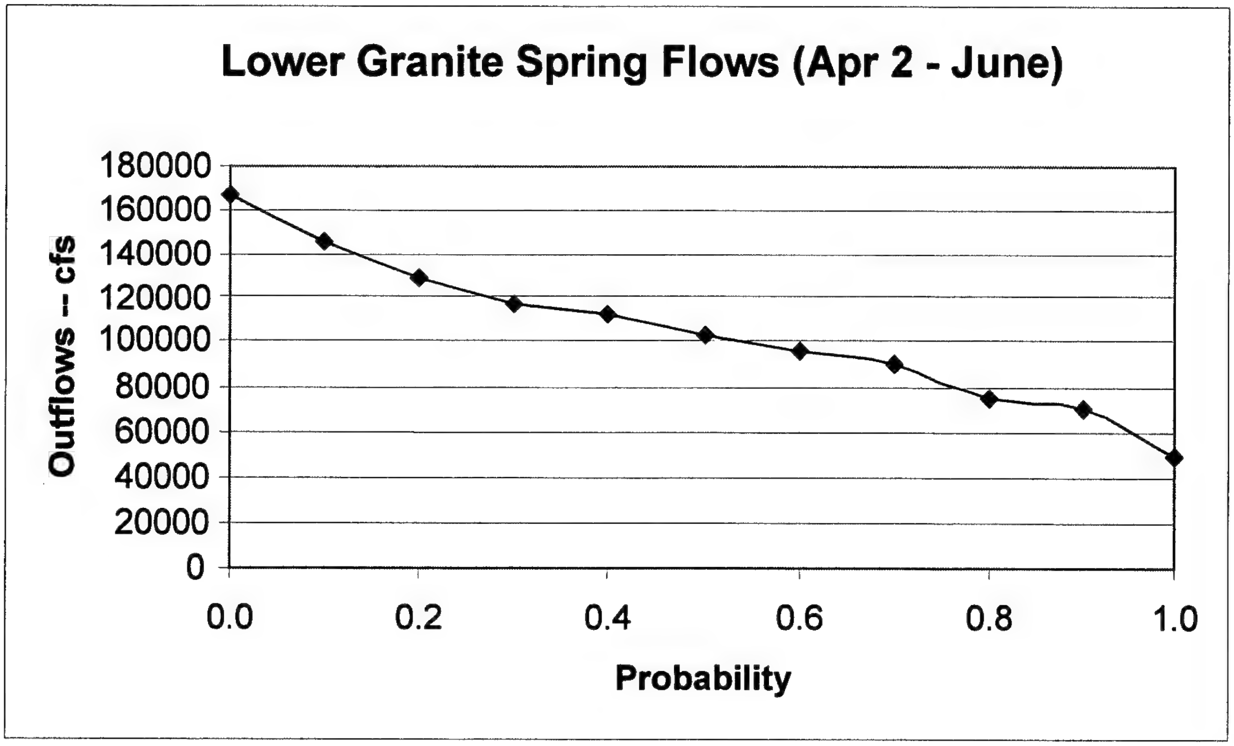


Figure B-1. Alternative A1 Graphs (continued)



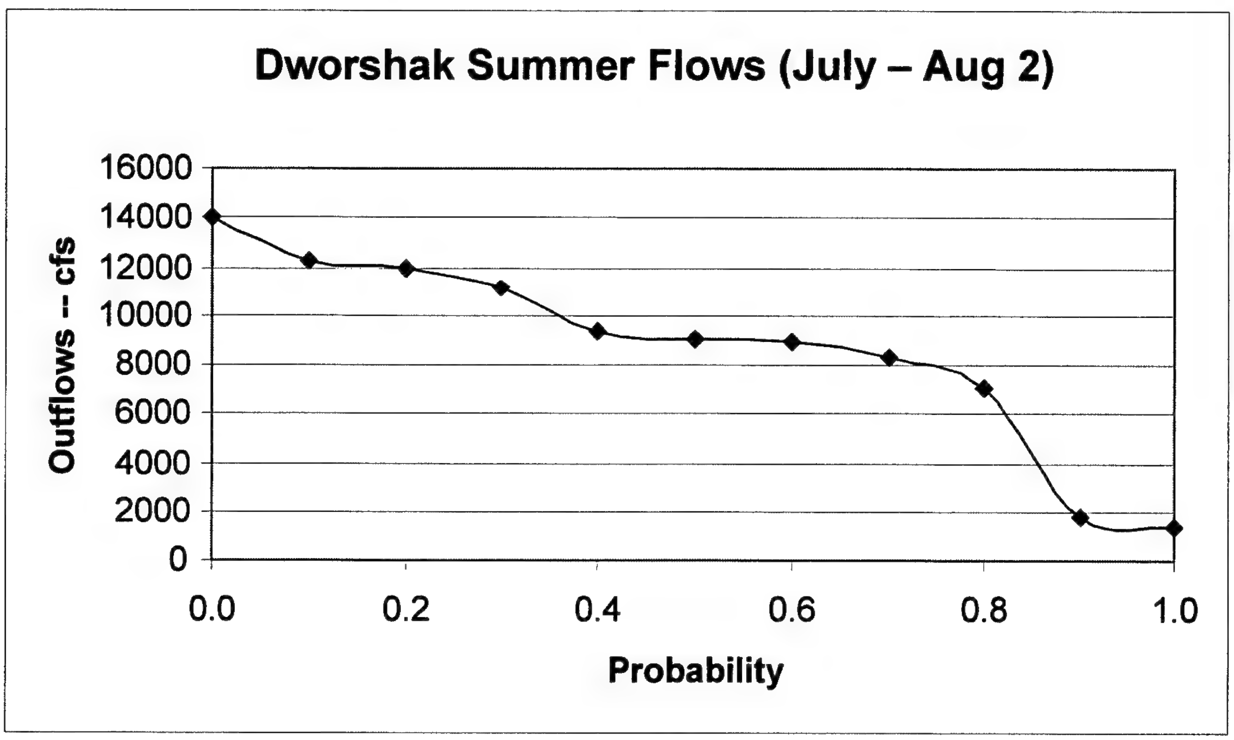


Figure B-1. Alternative A1 Graphs (continued)

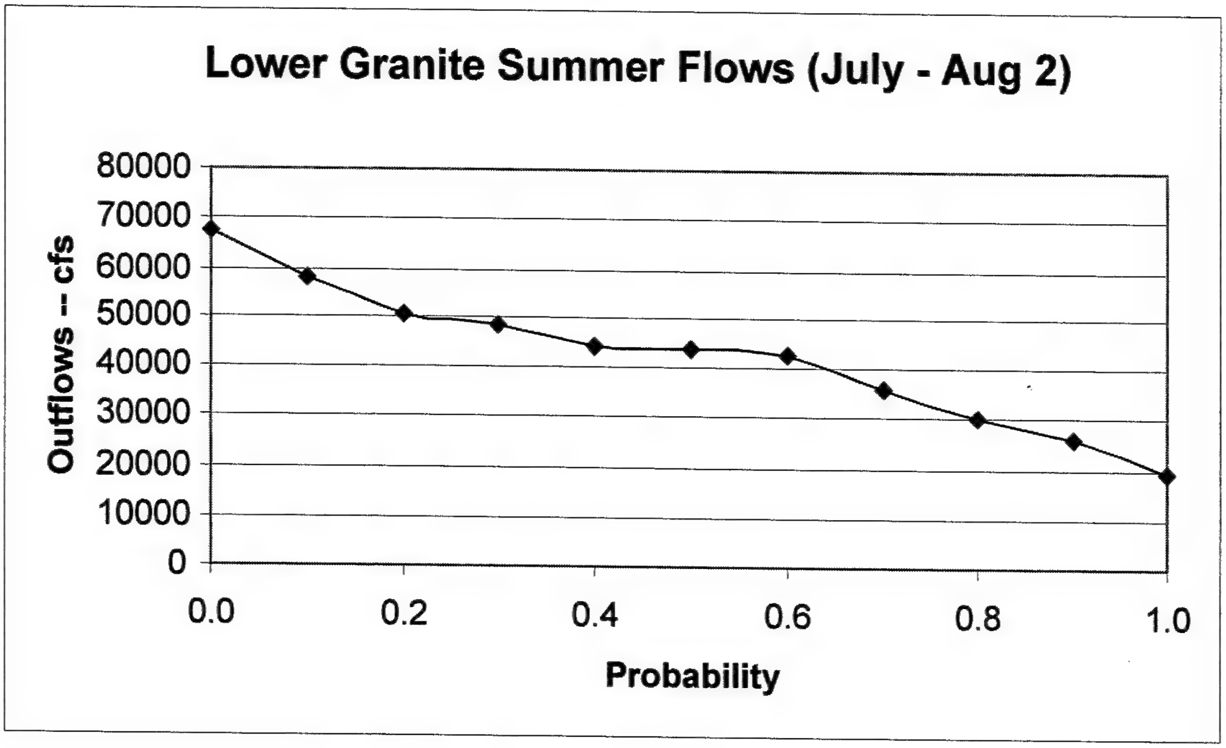
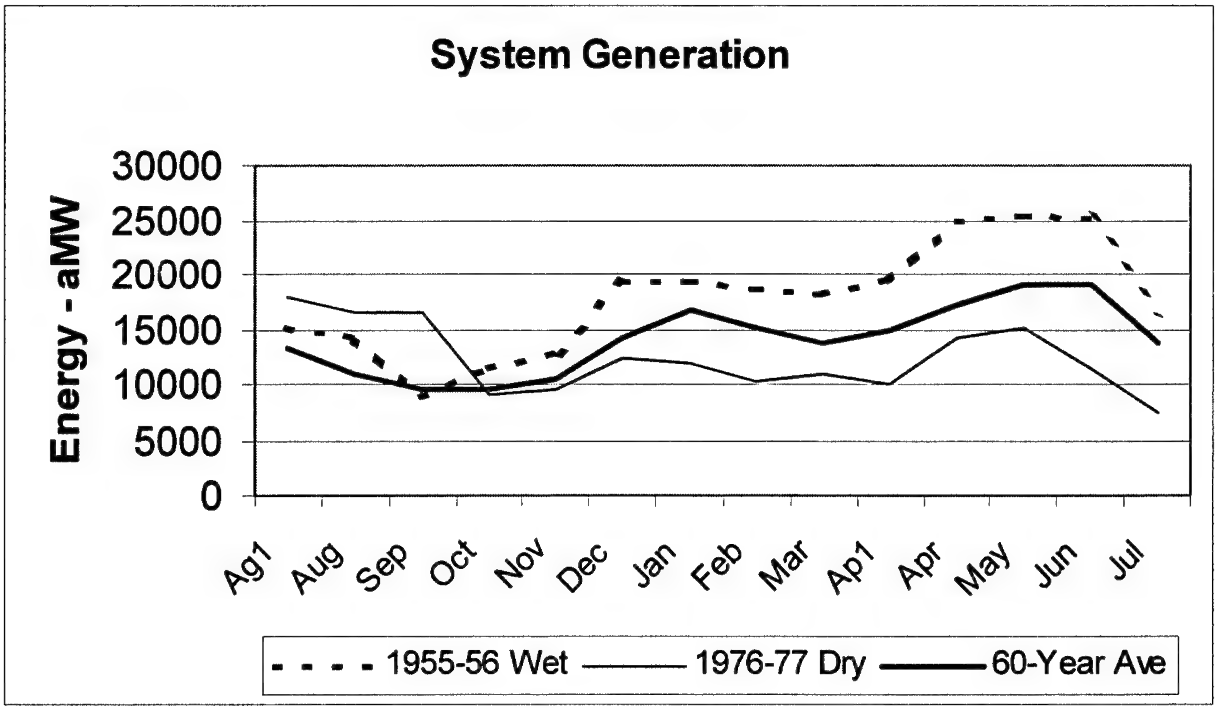


Figure B-2. Alternative A2 Graphs



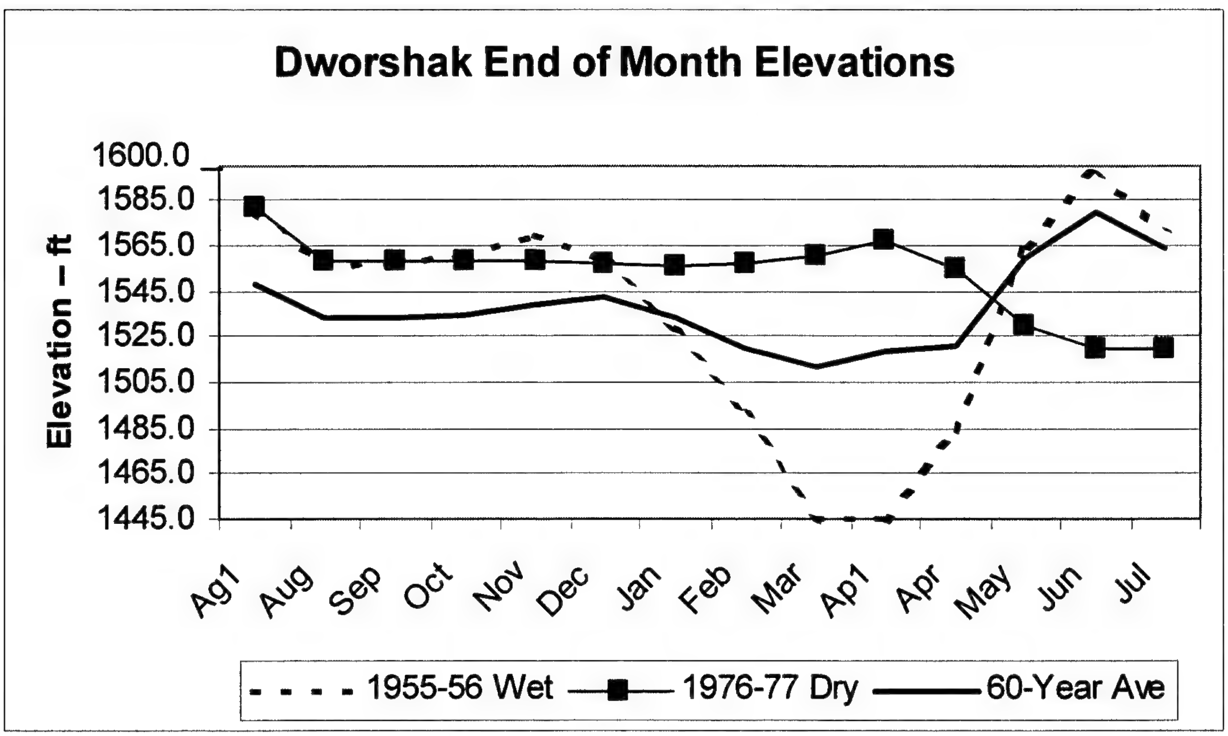
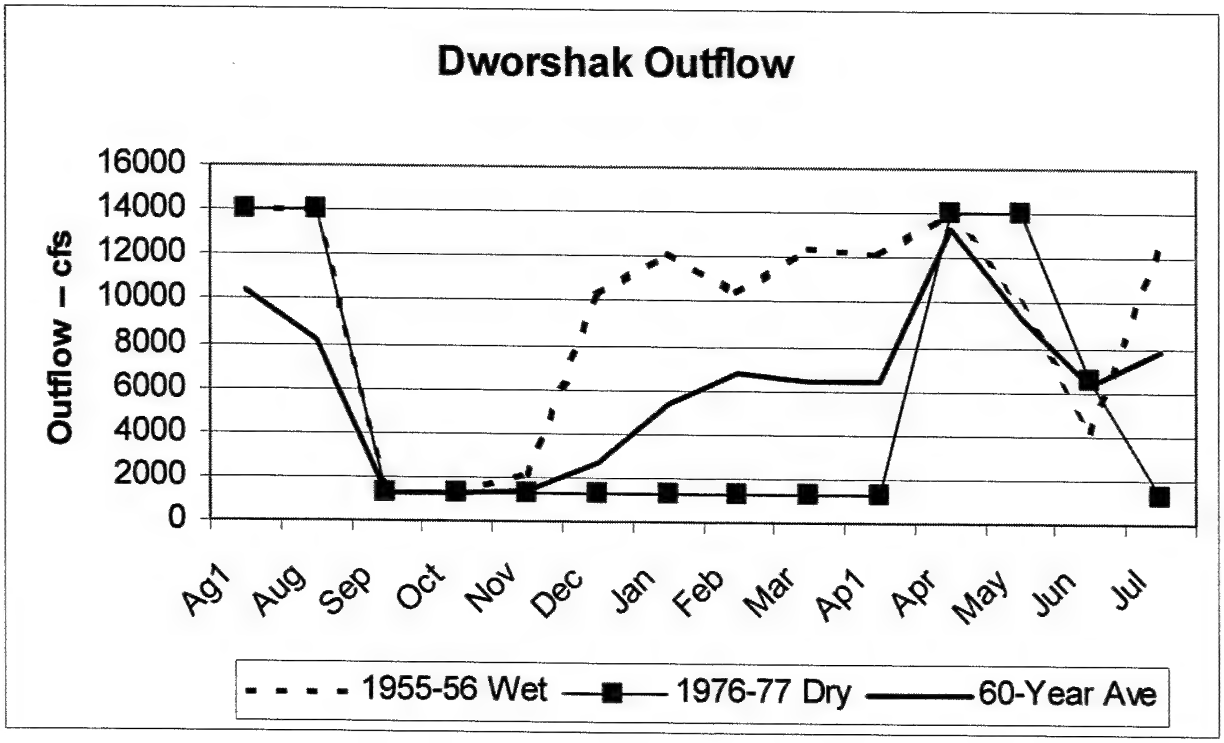


Figure B-2. Alternative A2 Graphs (continued)



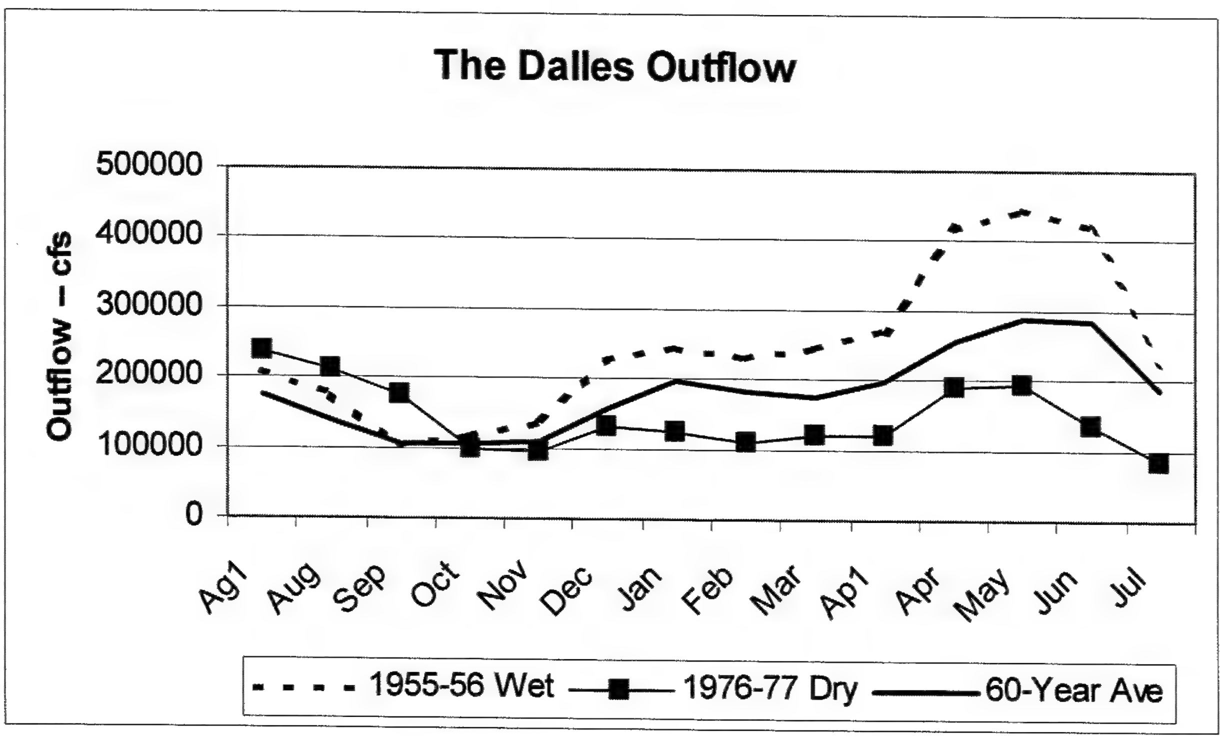
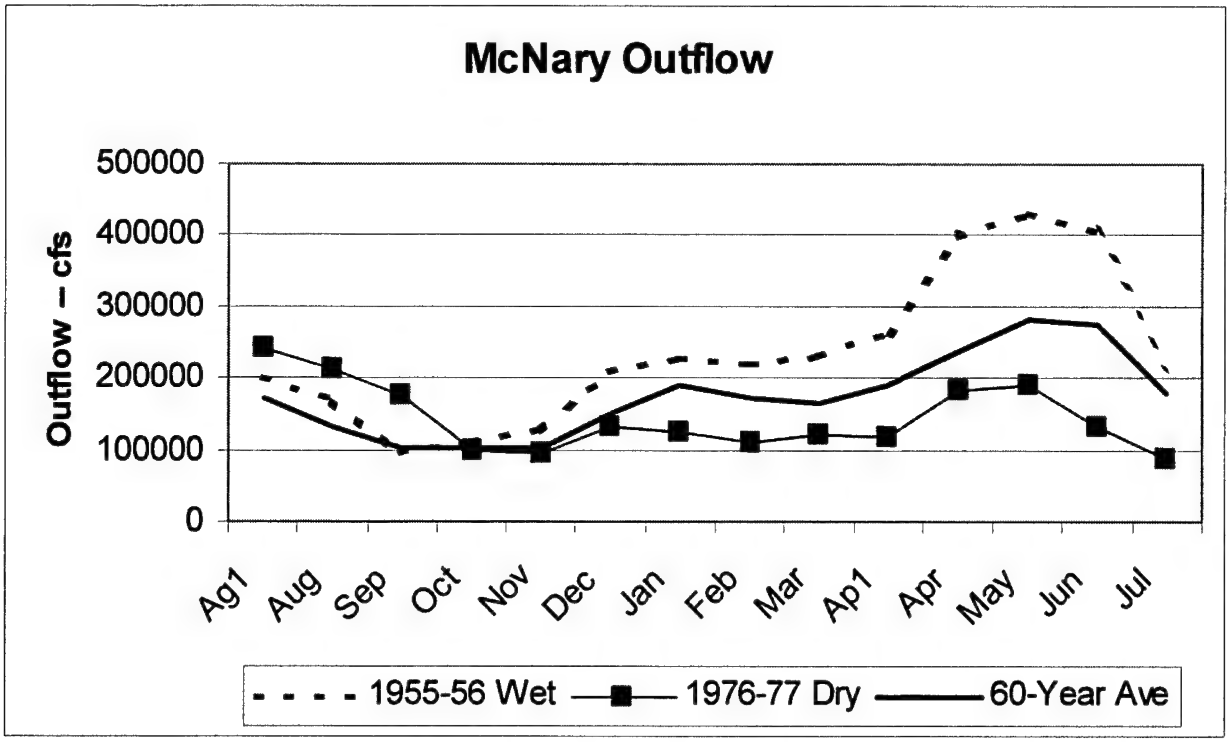


Figure B-2. Alternative A2 Graphs (continued)



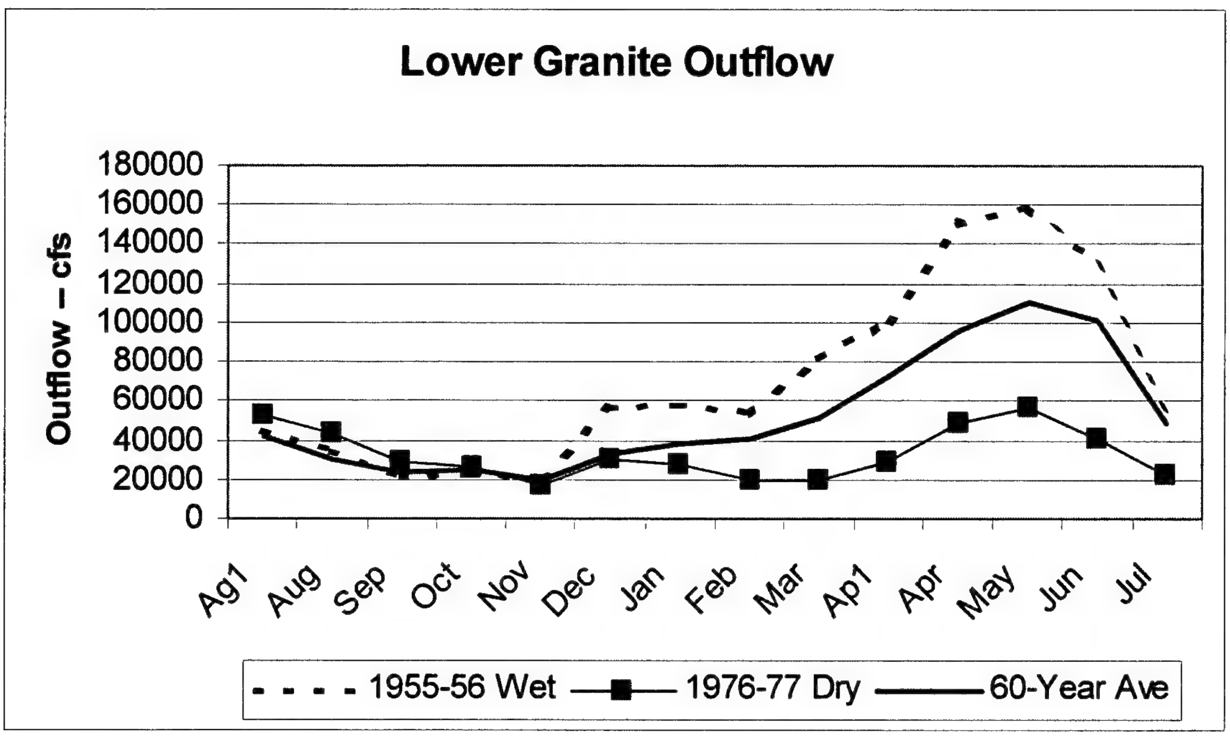
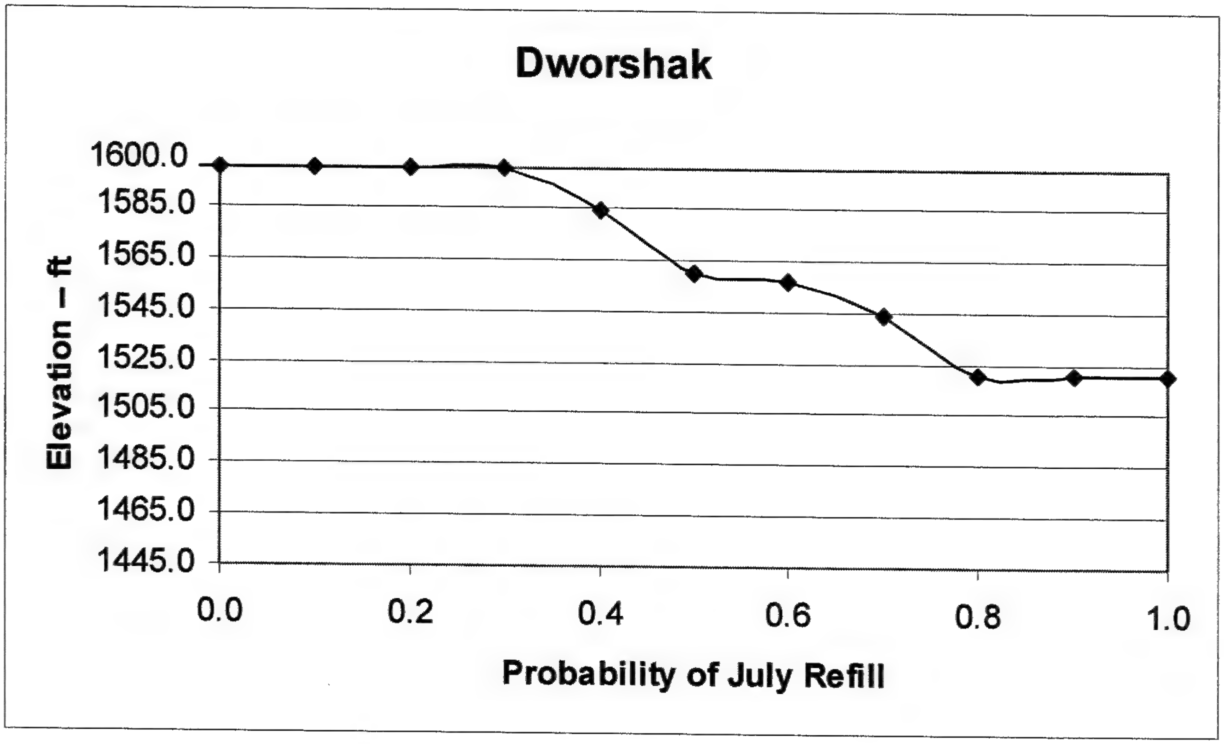


Figure B-2. Alternative A2 Graphs (continued)



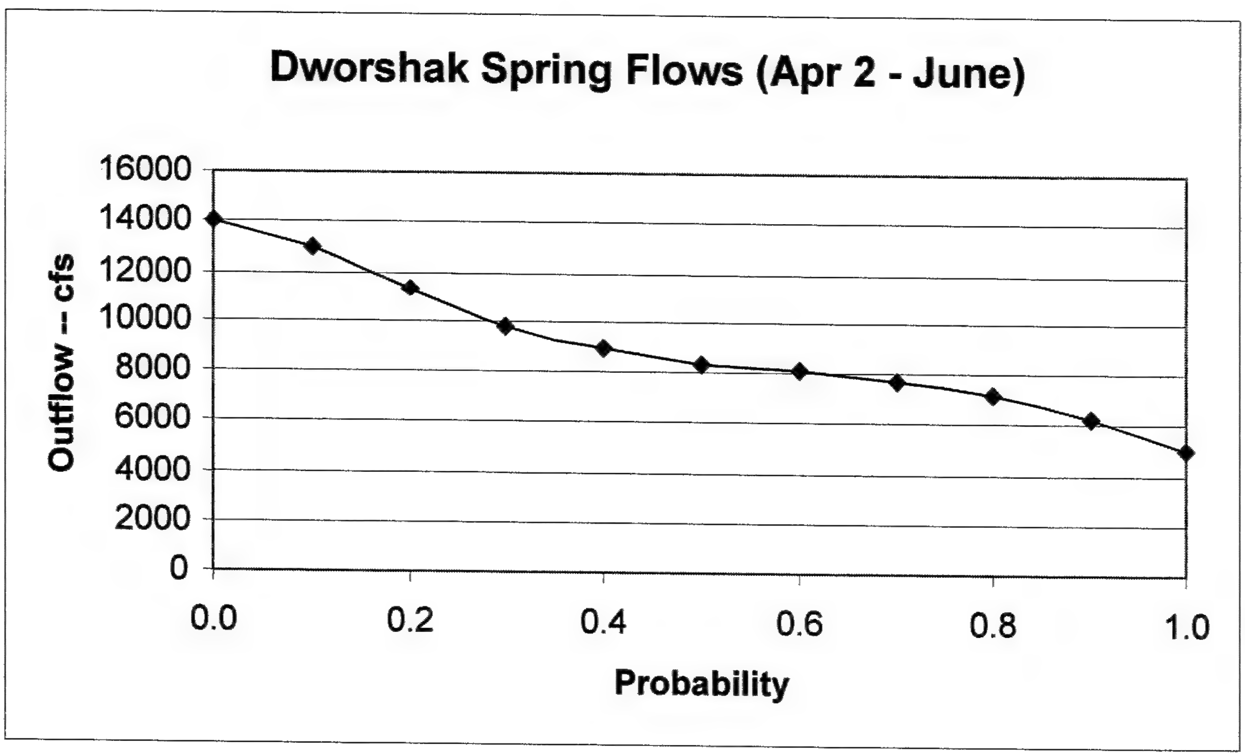
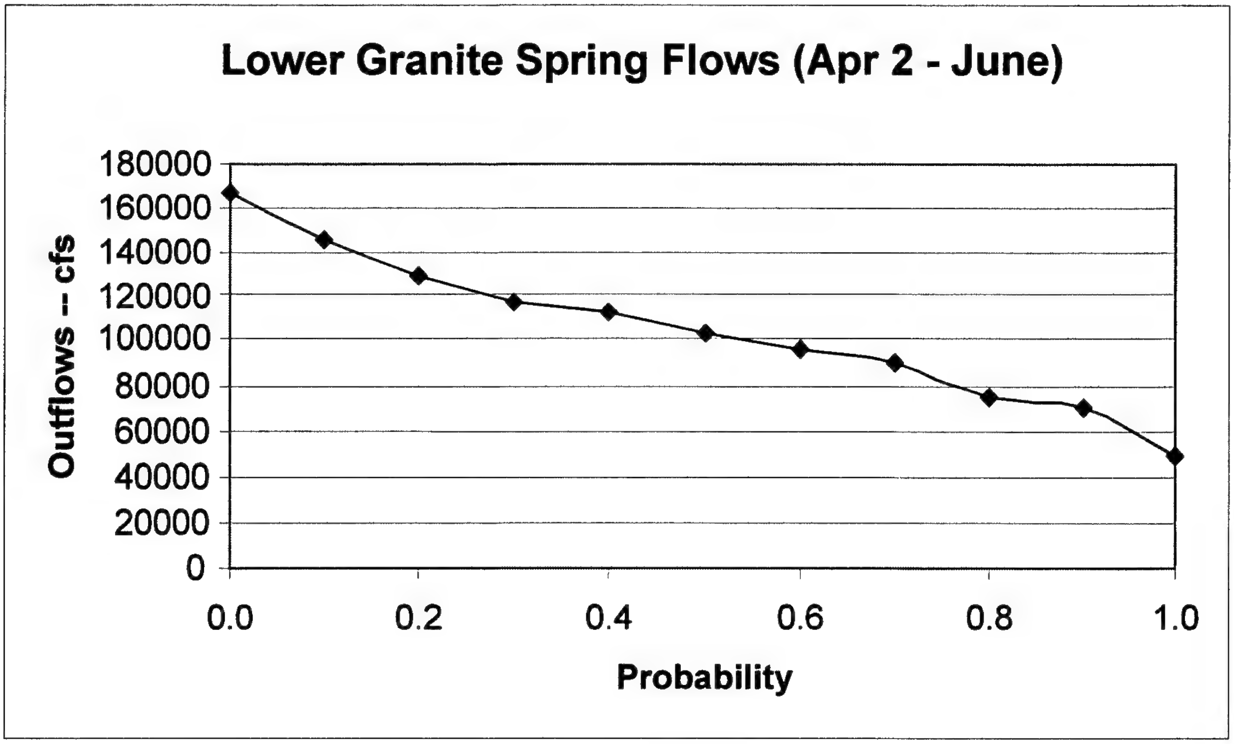


Figure B-2. Alternative A2 Graphs (continued)



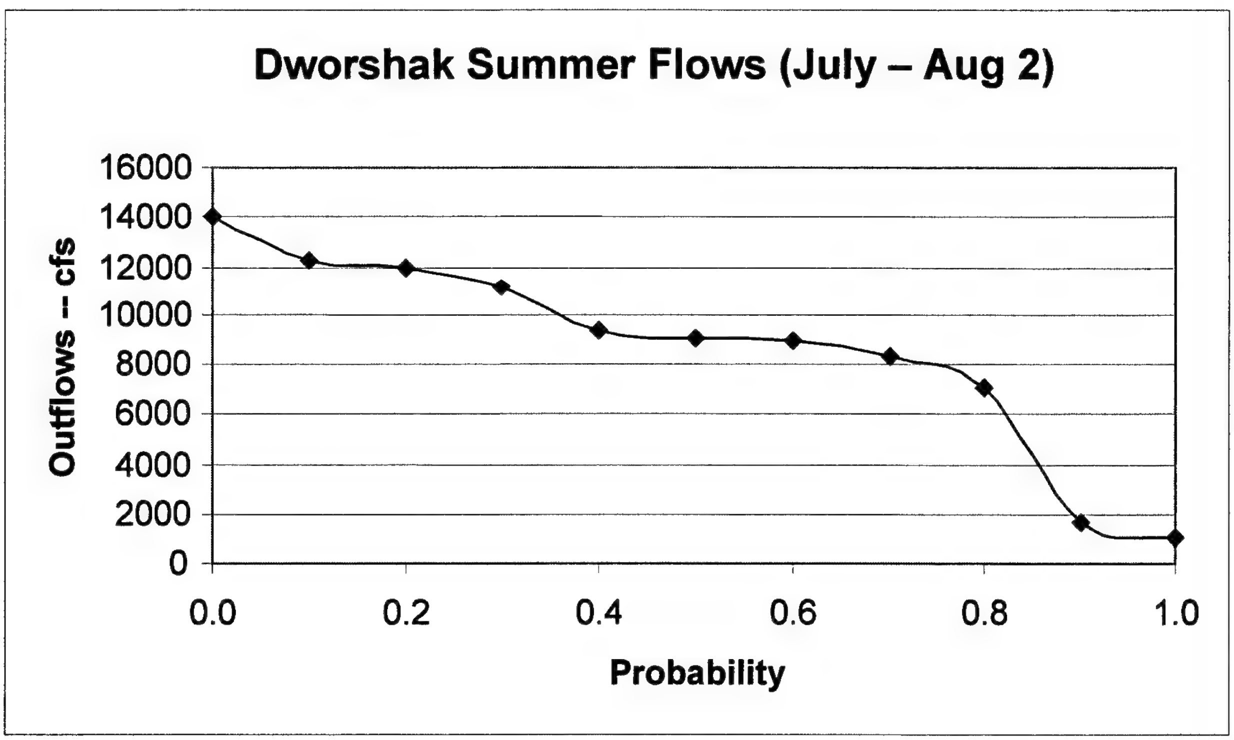


Figure B-2. Alternative A2 Graphs (continued)

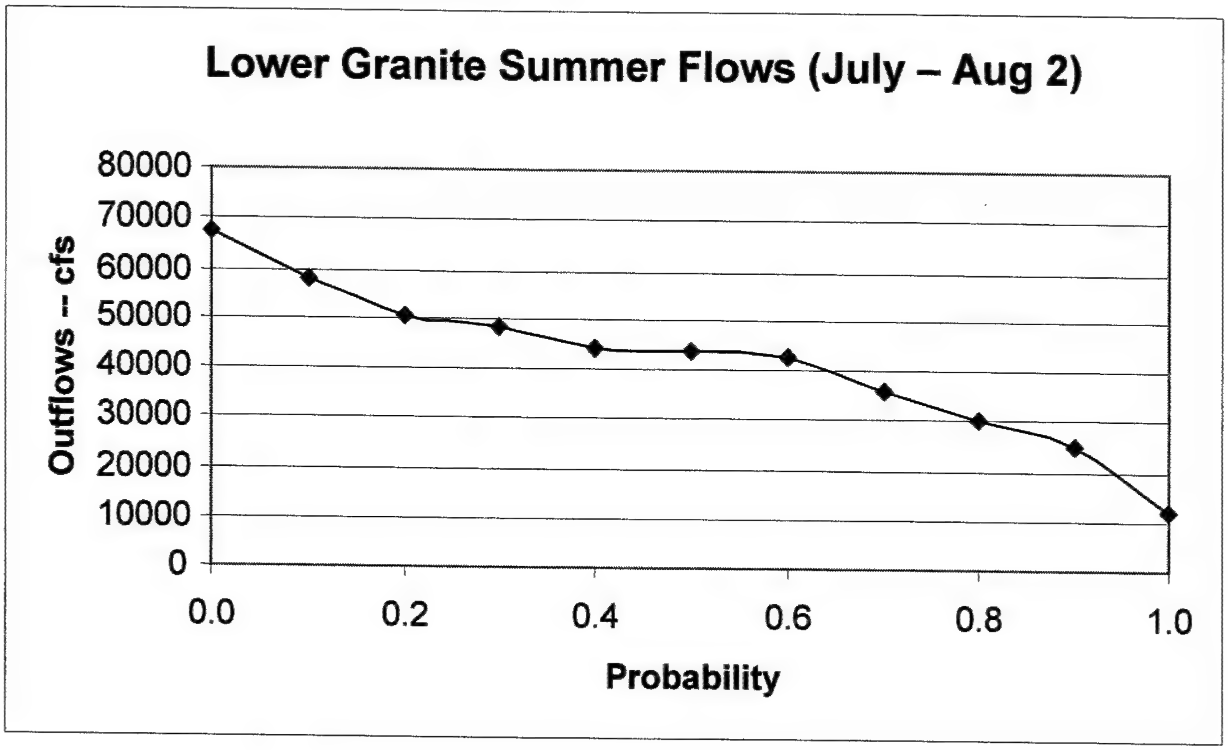
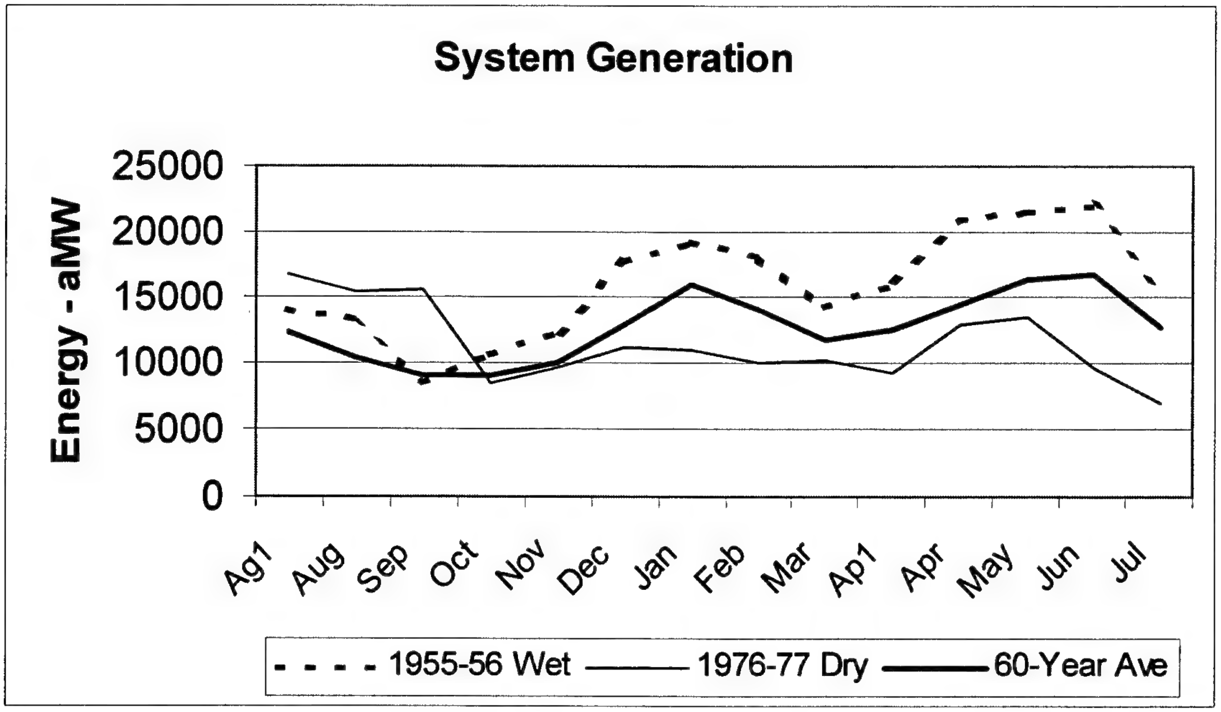


Figure B-3. Alternative A3 Graphs



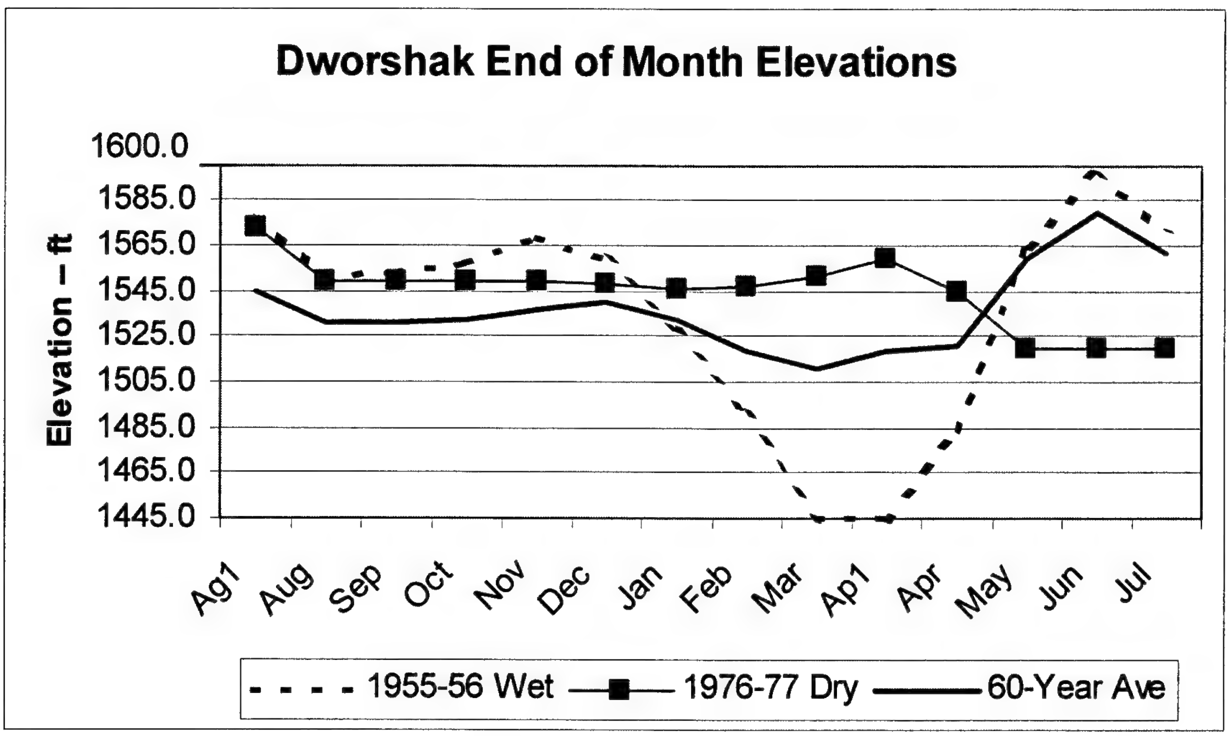
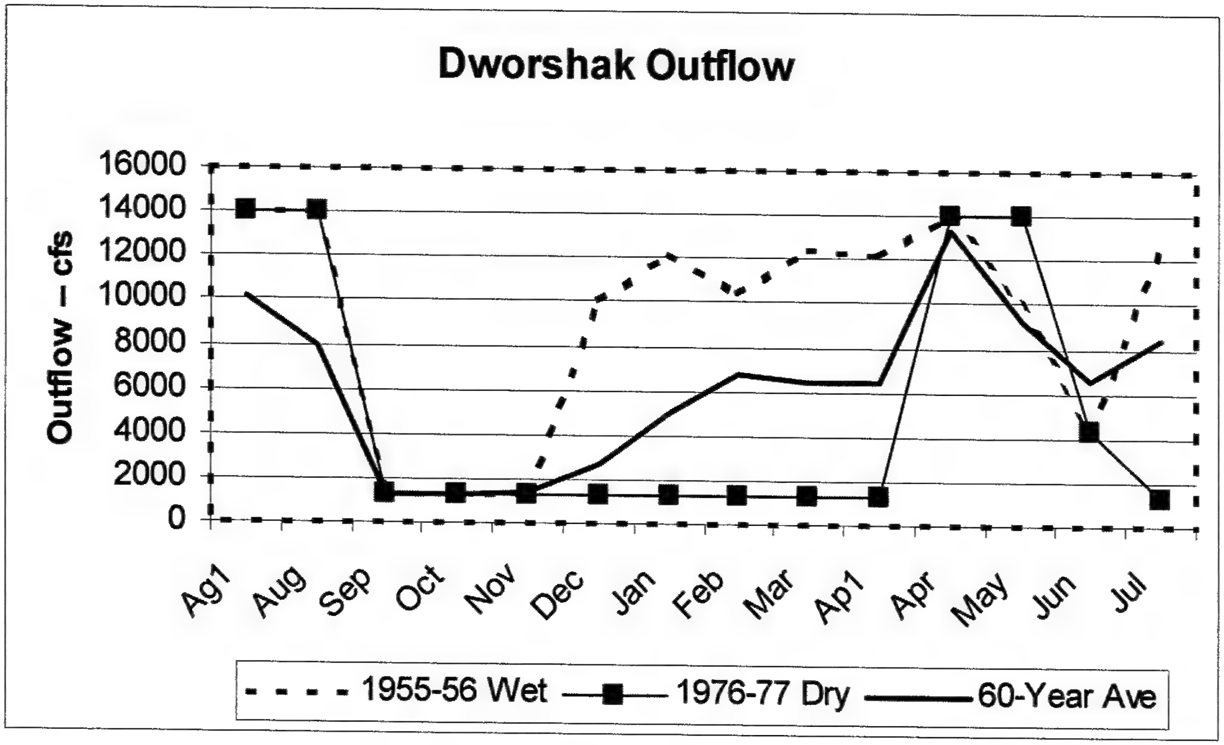


Figure B-3. Alternative A3 Graphs (continued)



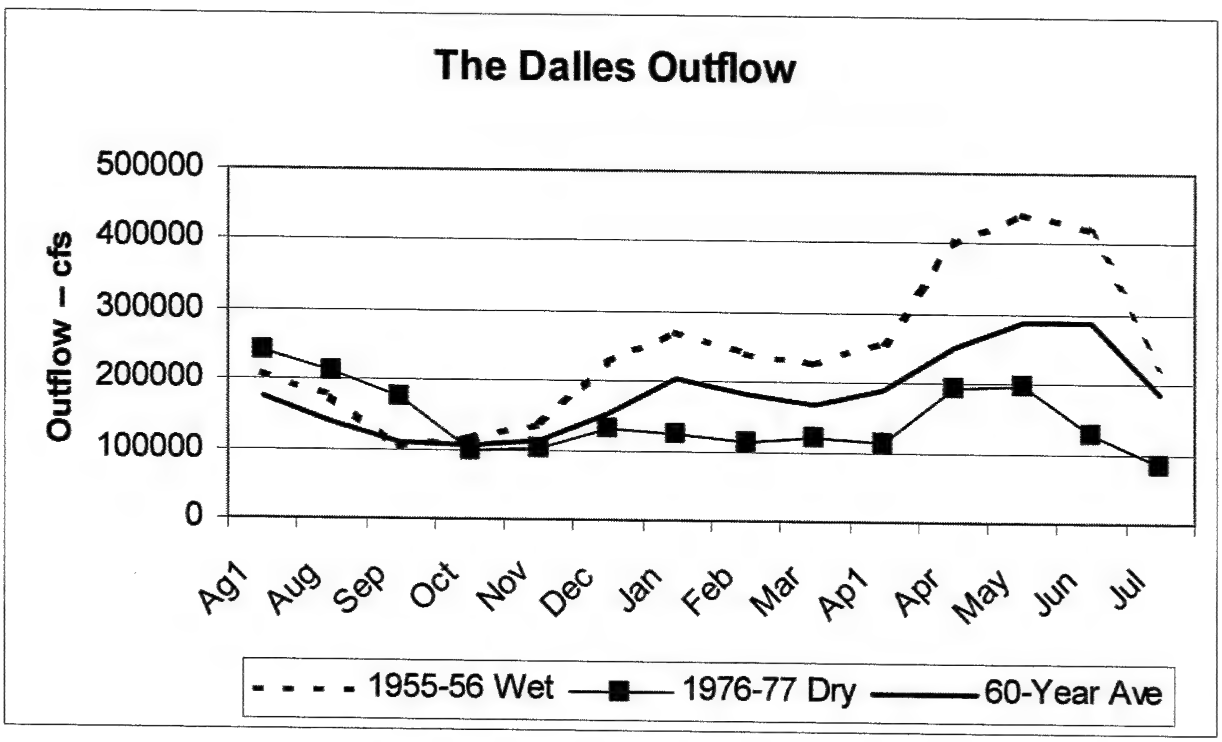
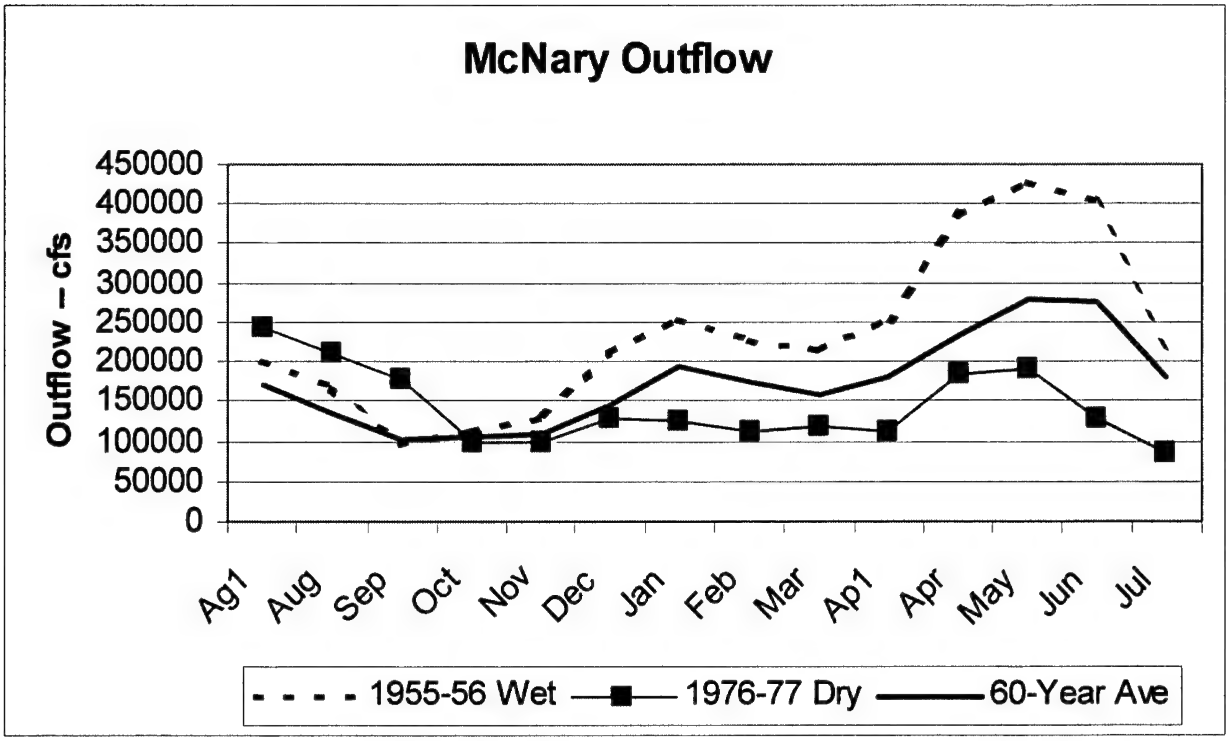


Figure B-3. Alternative A3 Graphs (continued)



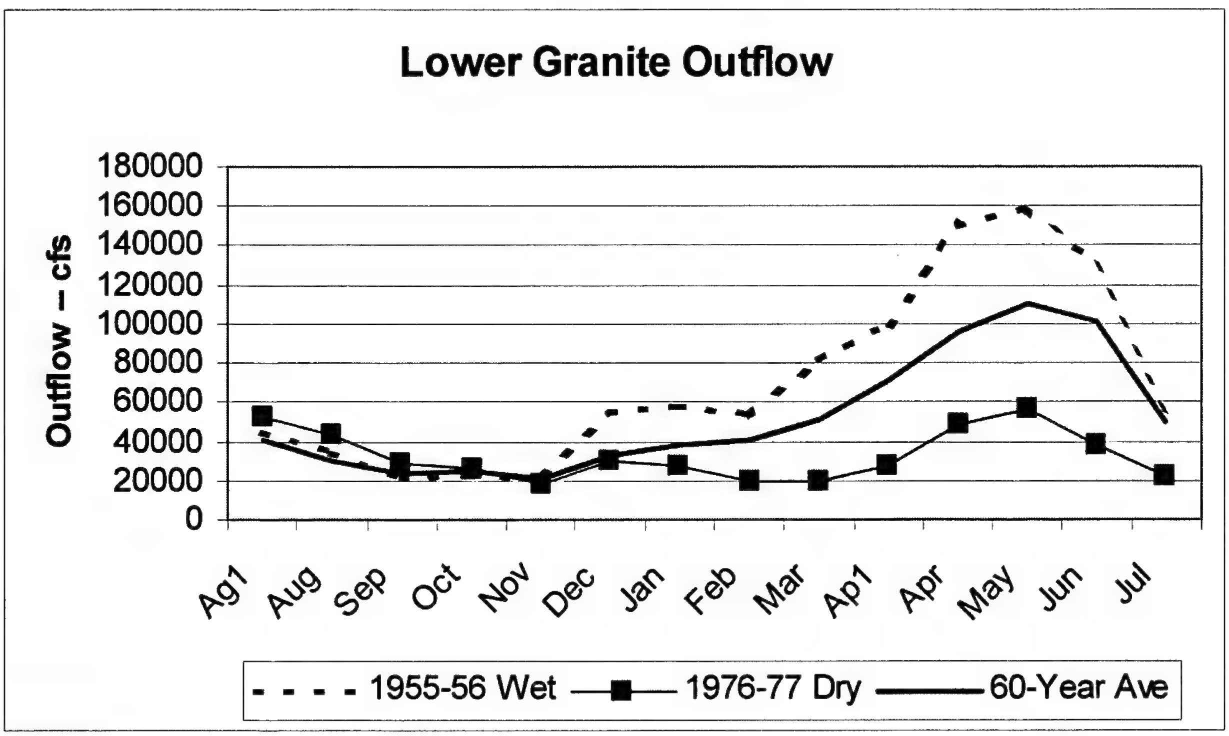
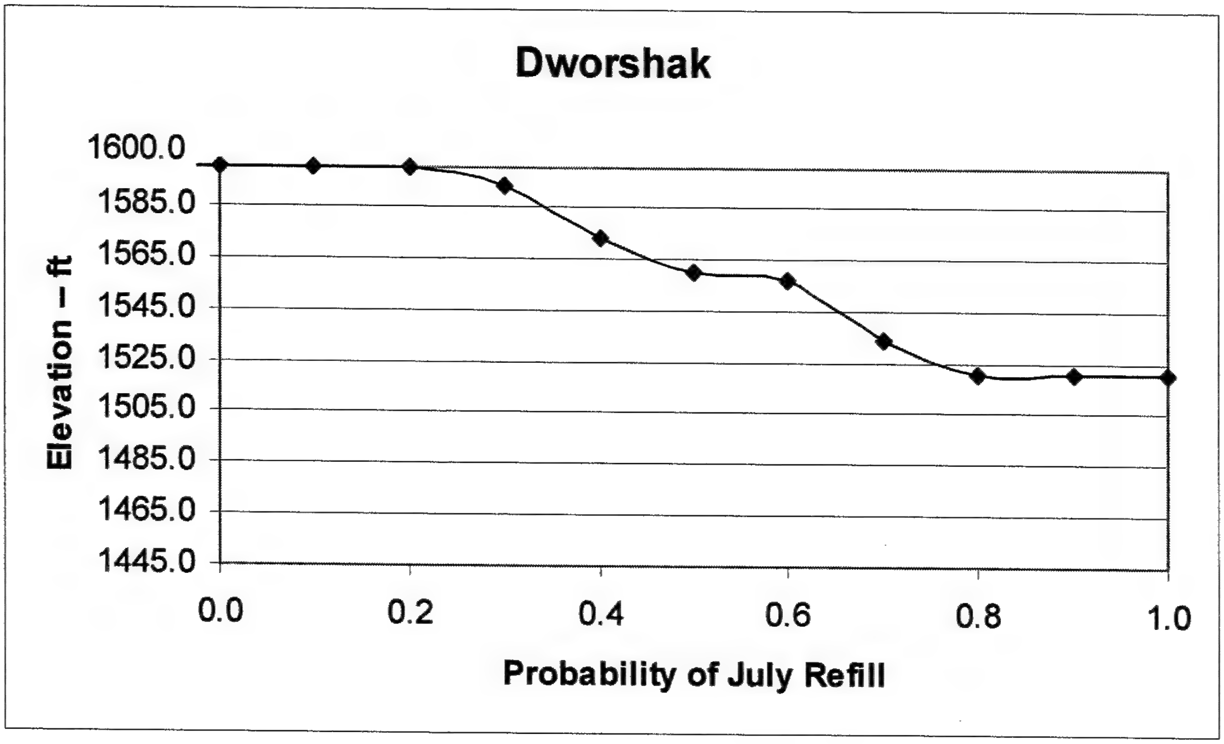


Figure B-3. Alternative A3 Graphs (continued)



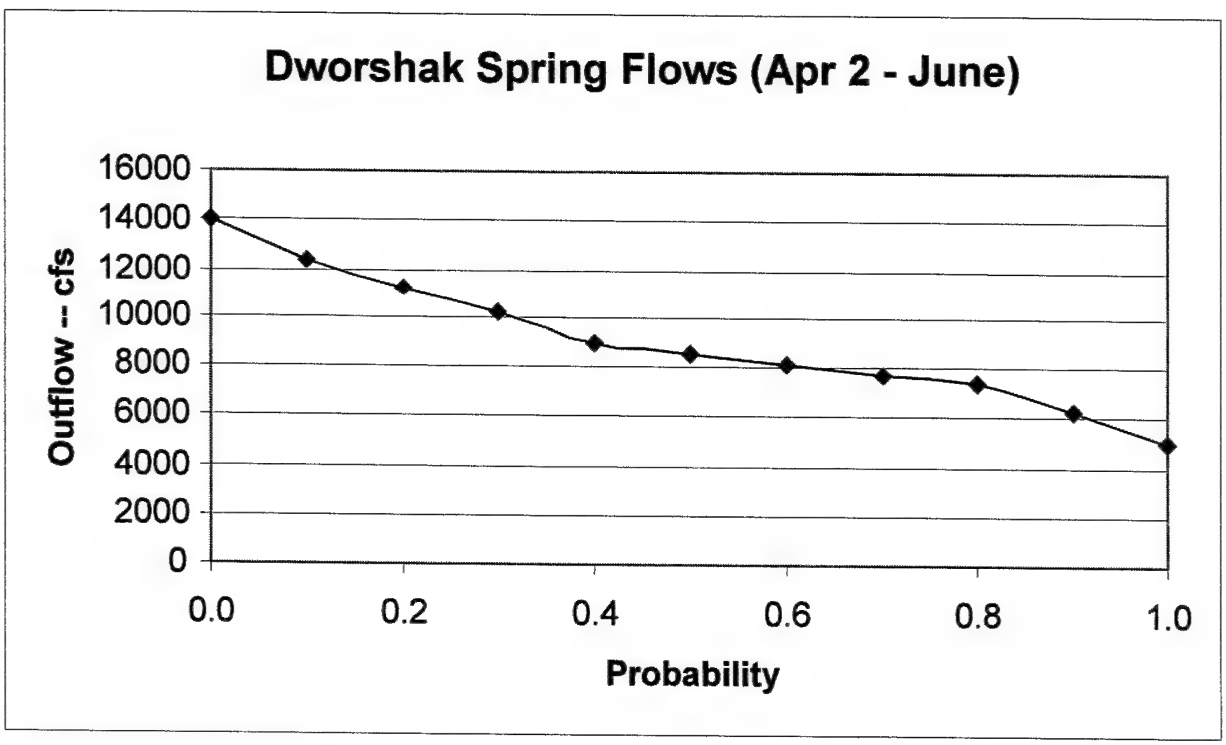
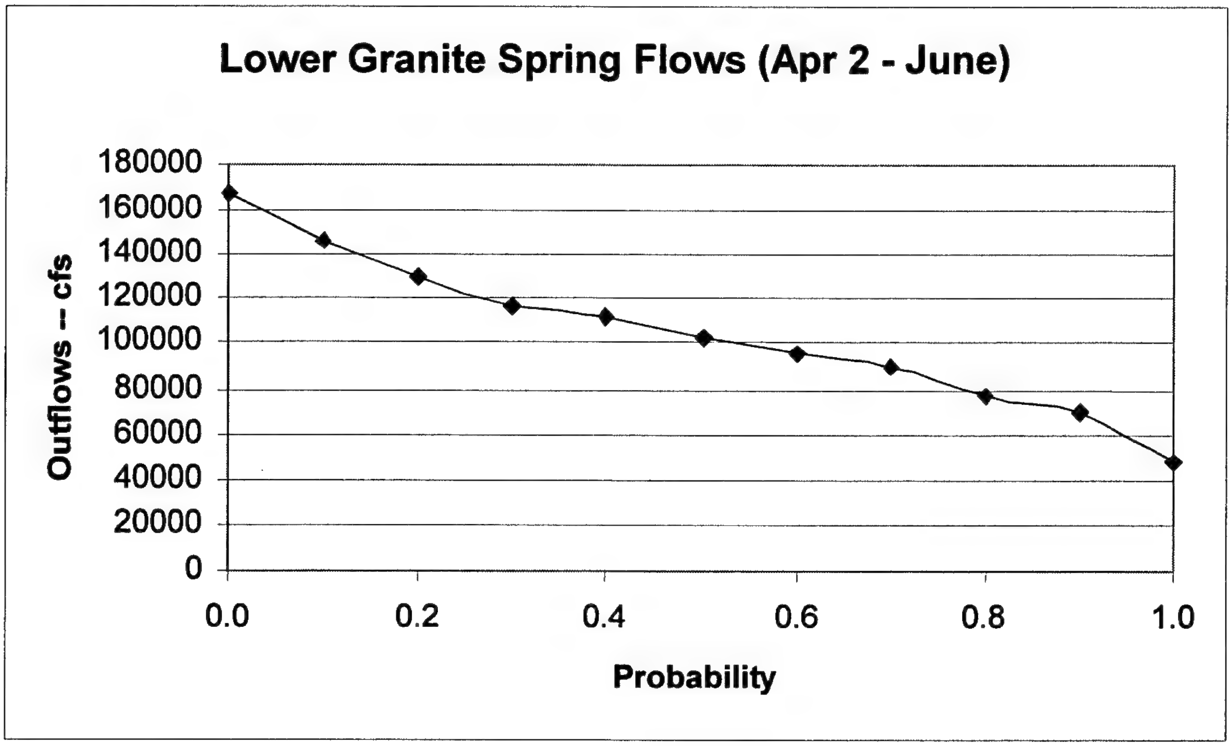


Figure B-3. Alternative A3 Graphs (continued)



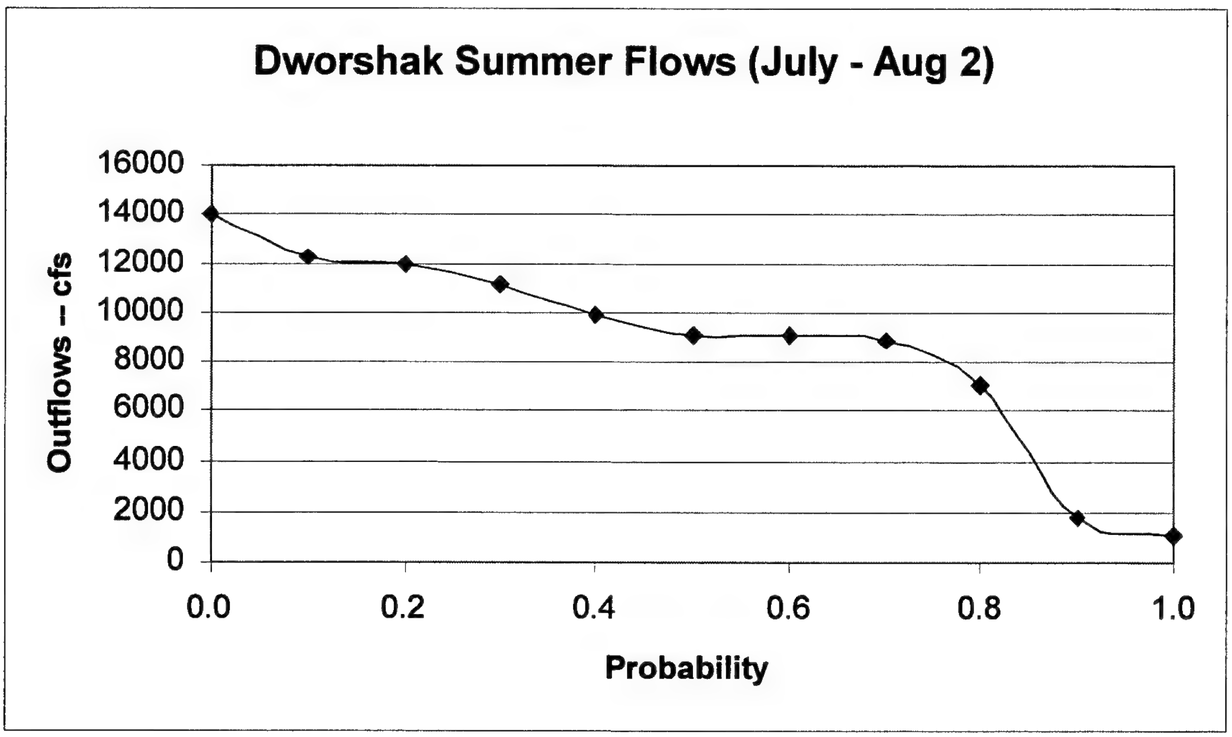


Figure B-3. Alternative A3 Graphs (continued)

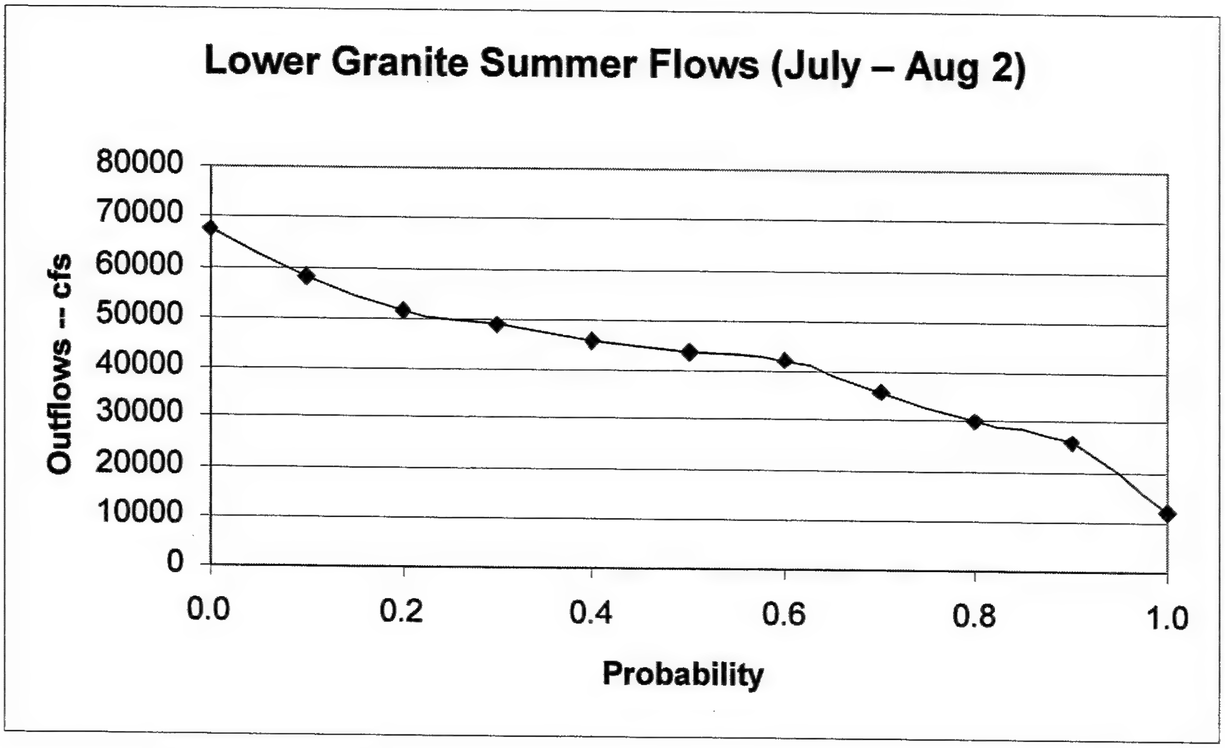
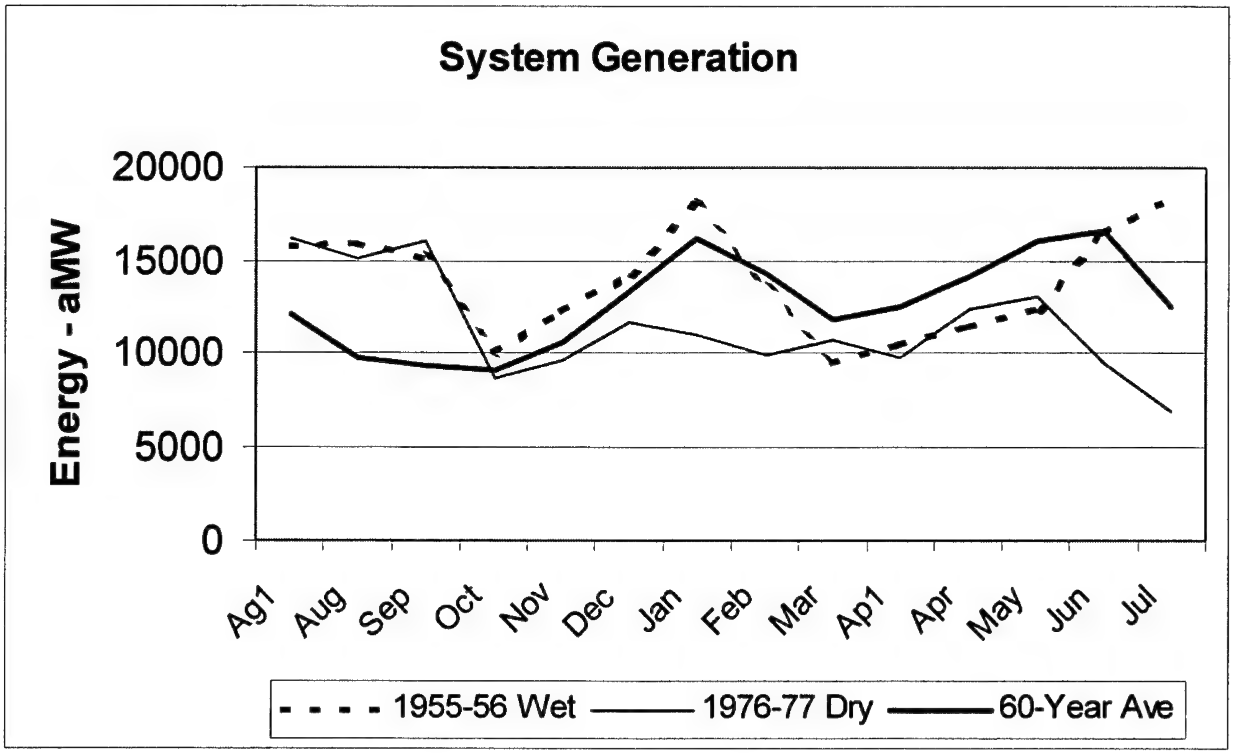


Figure B-4 Alternative A5 Graphs



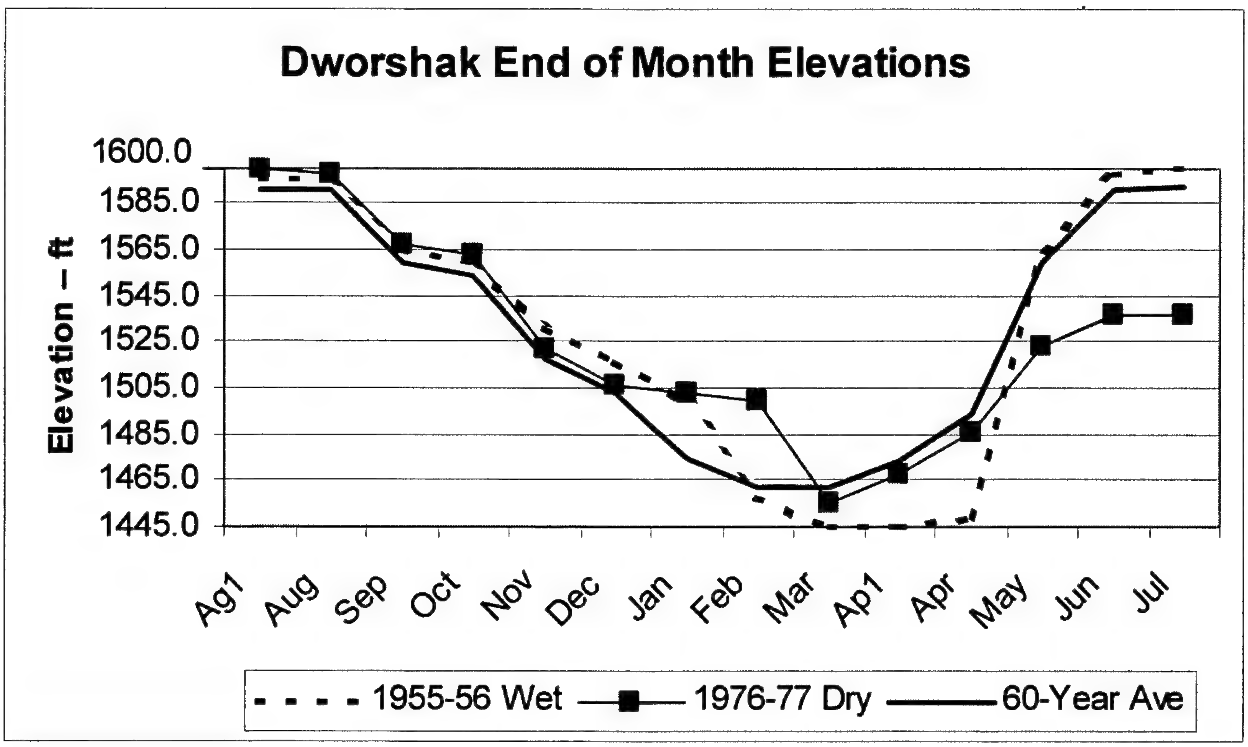
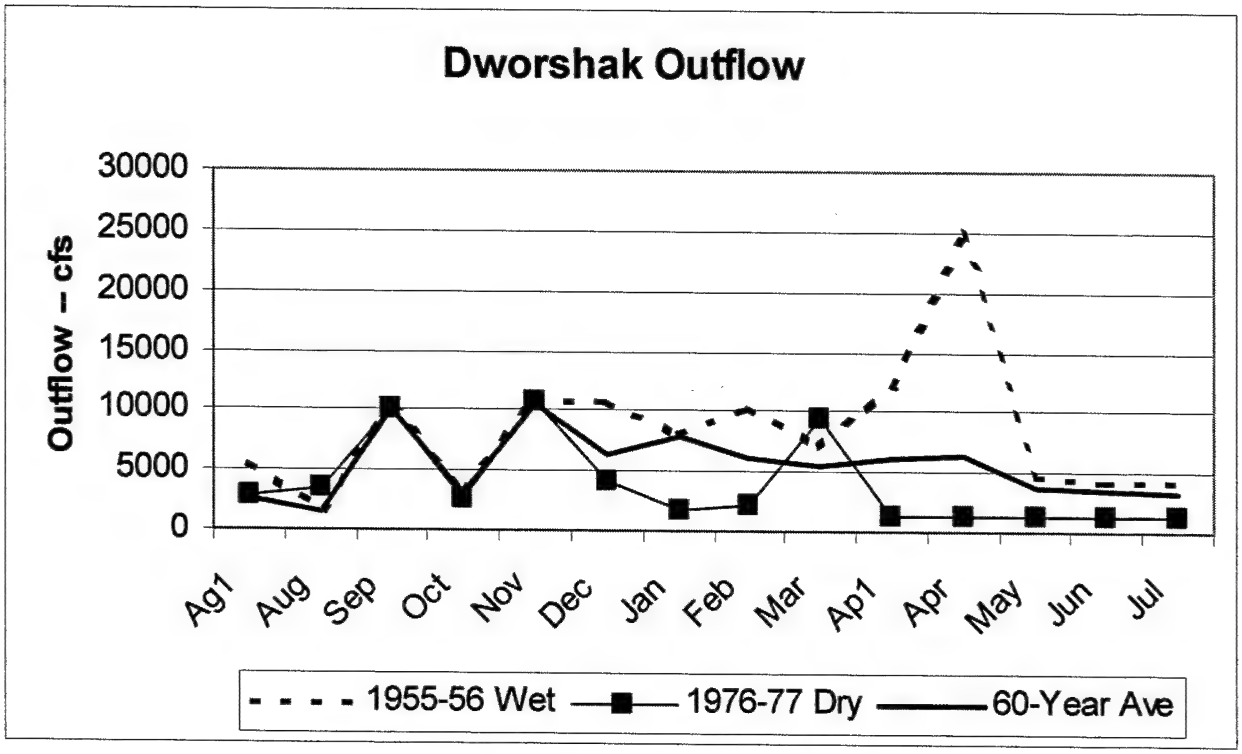


Figure B-4 Alternative A5 Graphs (continued)



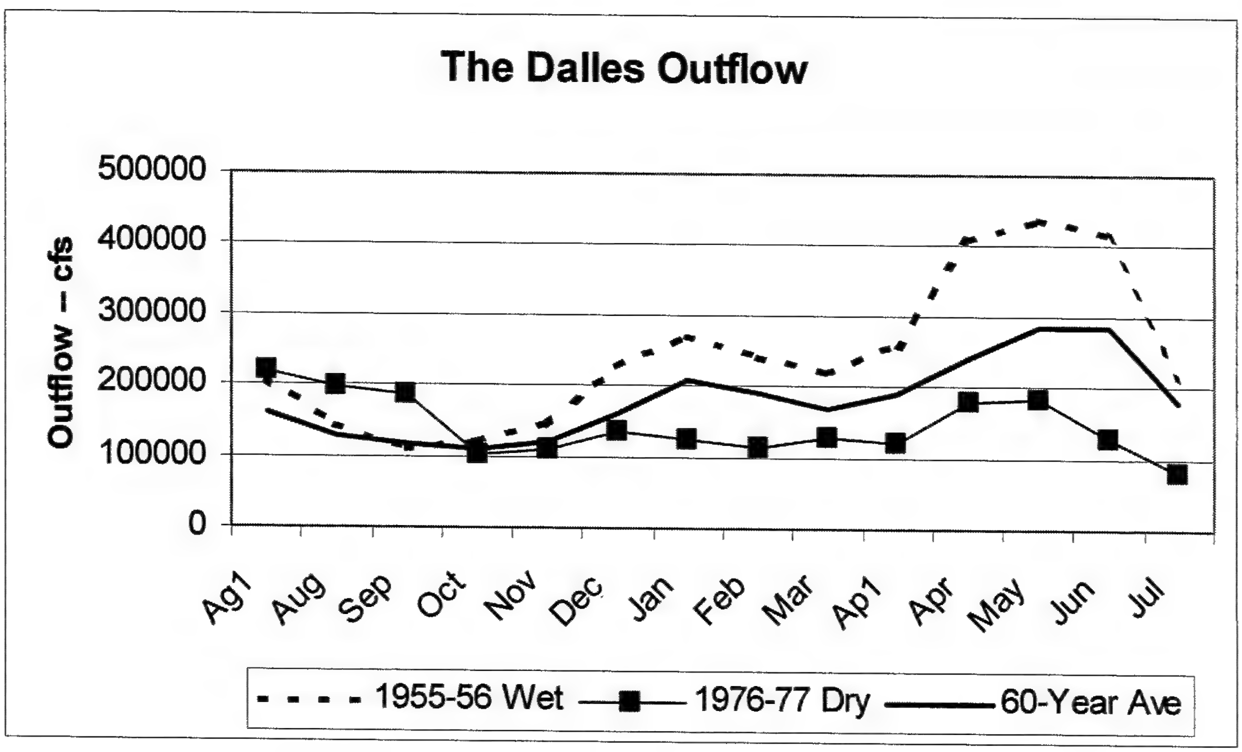
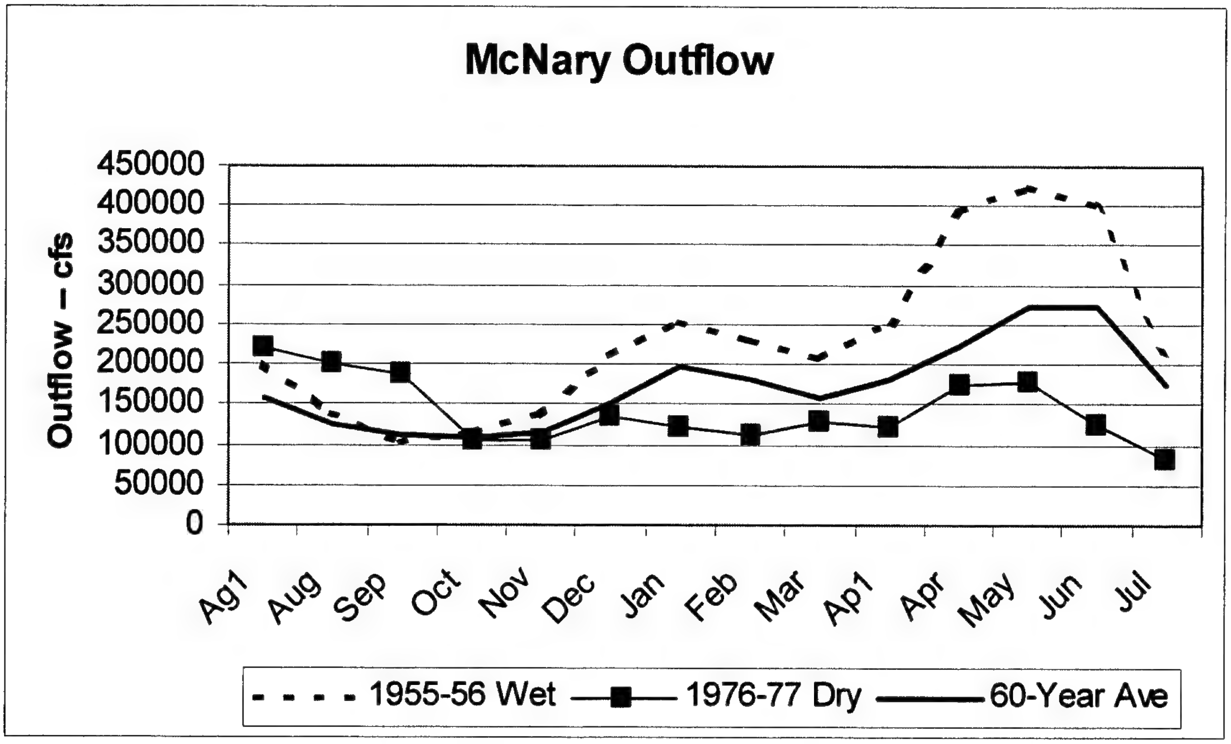


Figure B-4 Alternative A5 Graphs (continued)



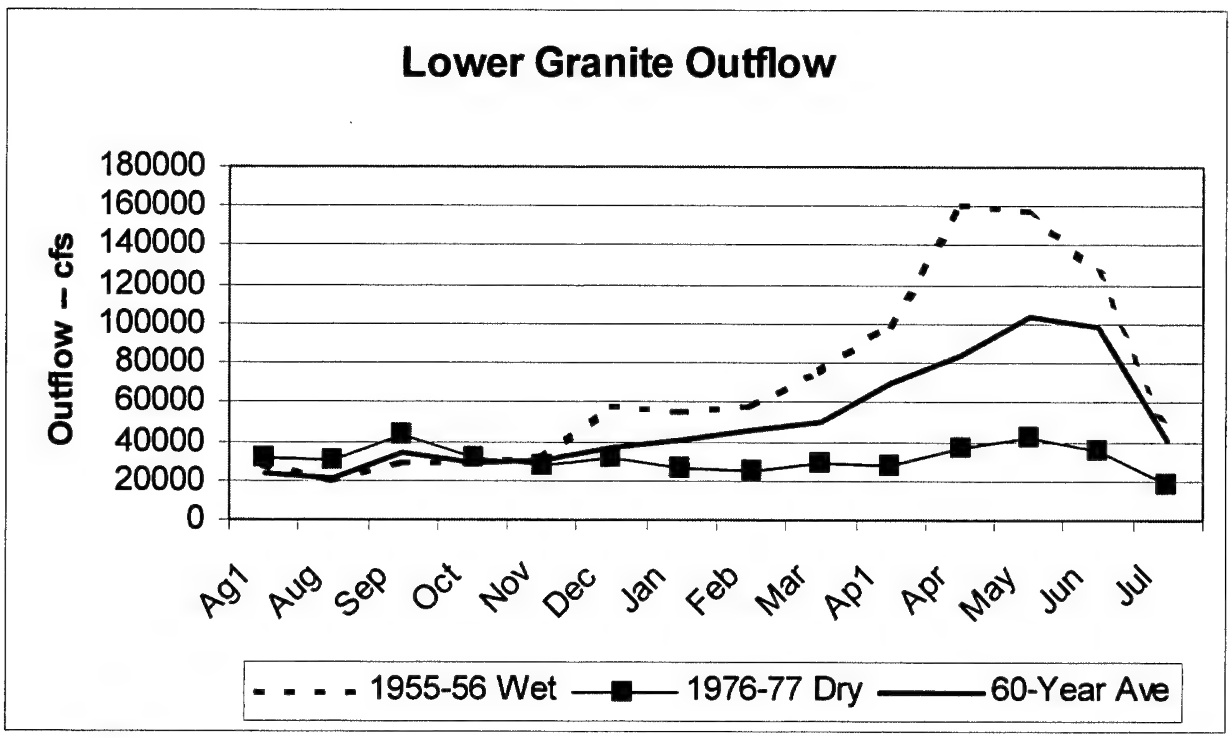
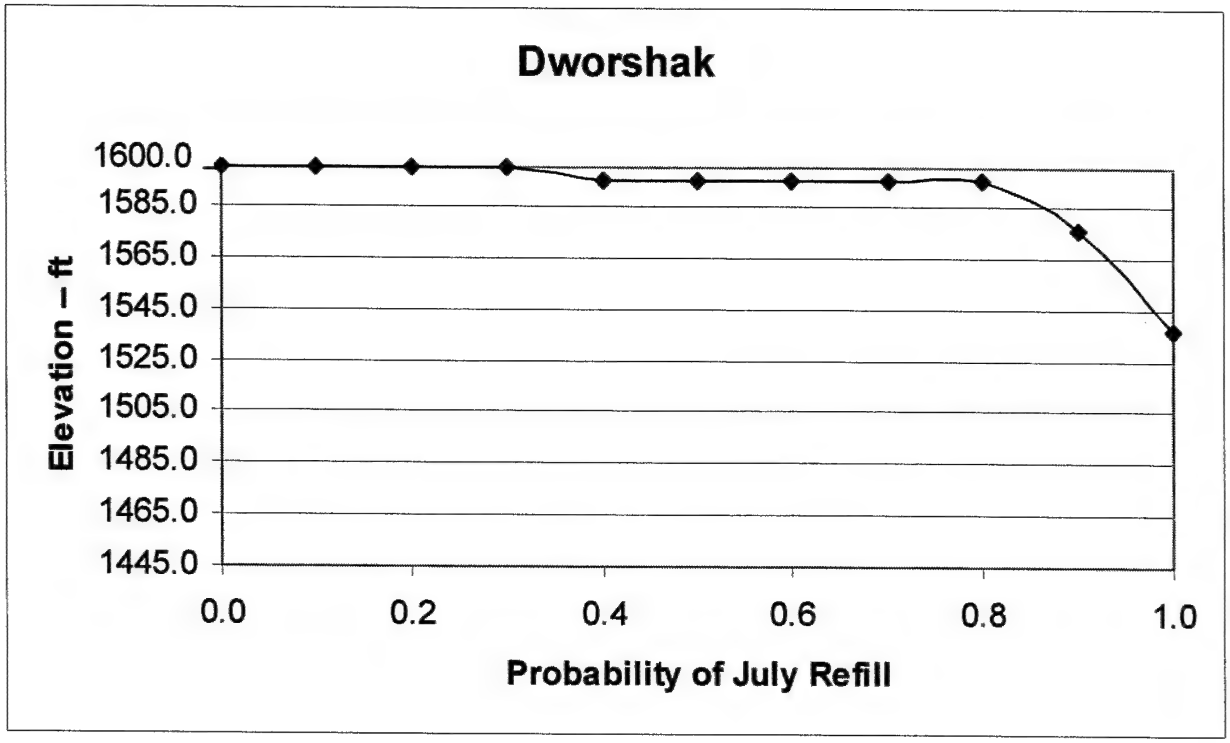


Figure B-4 Alternative A5 Graphs (continued)



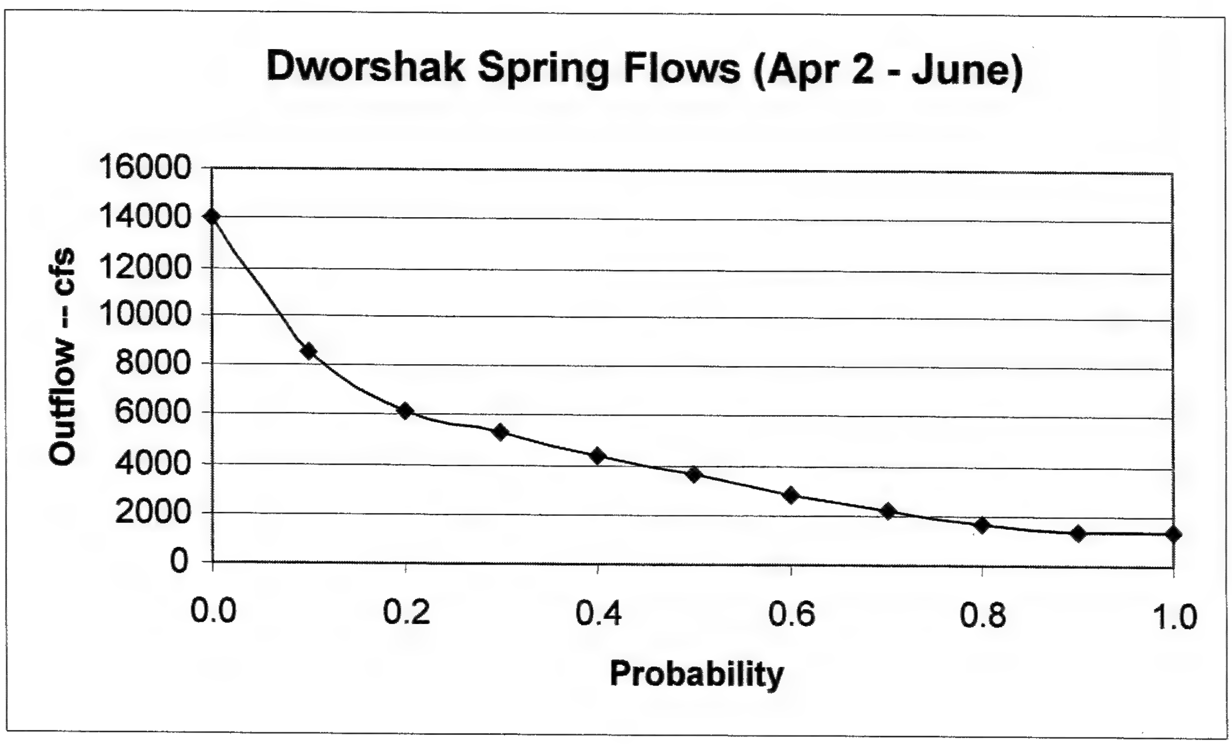
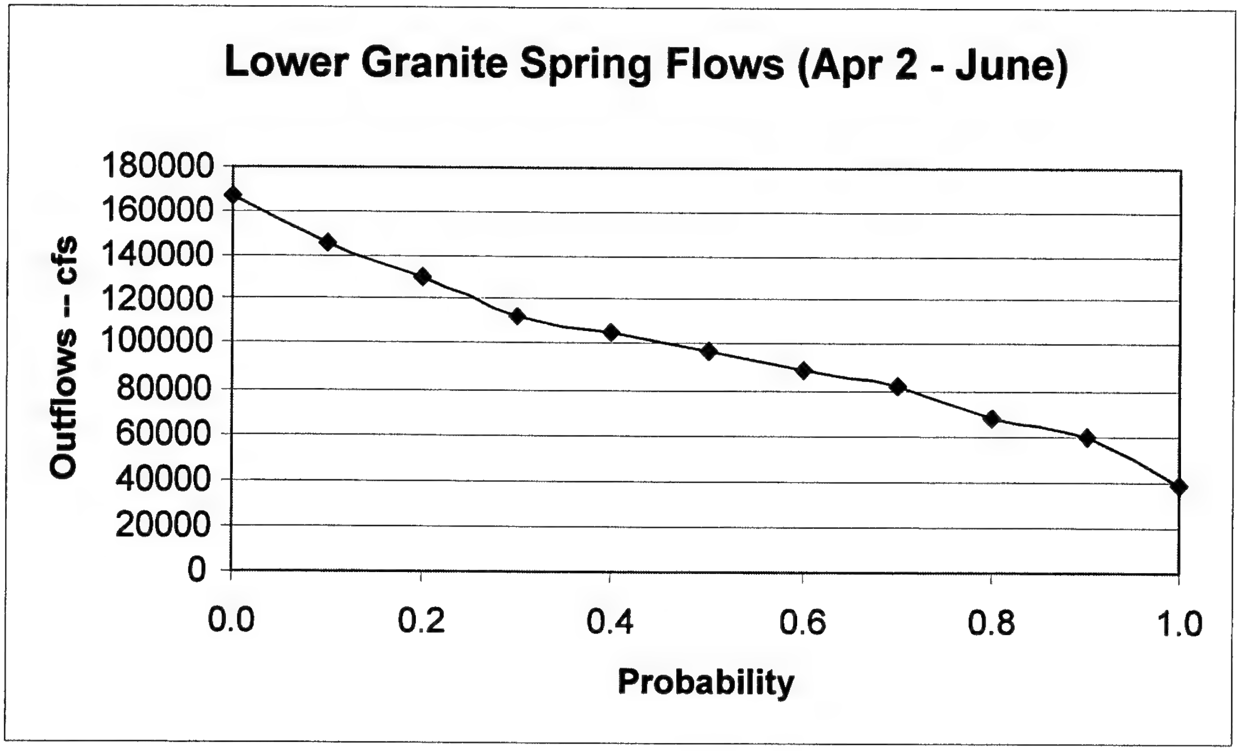


Figure B-4 Alternative A5 Graphs (continued)



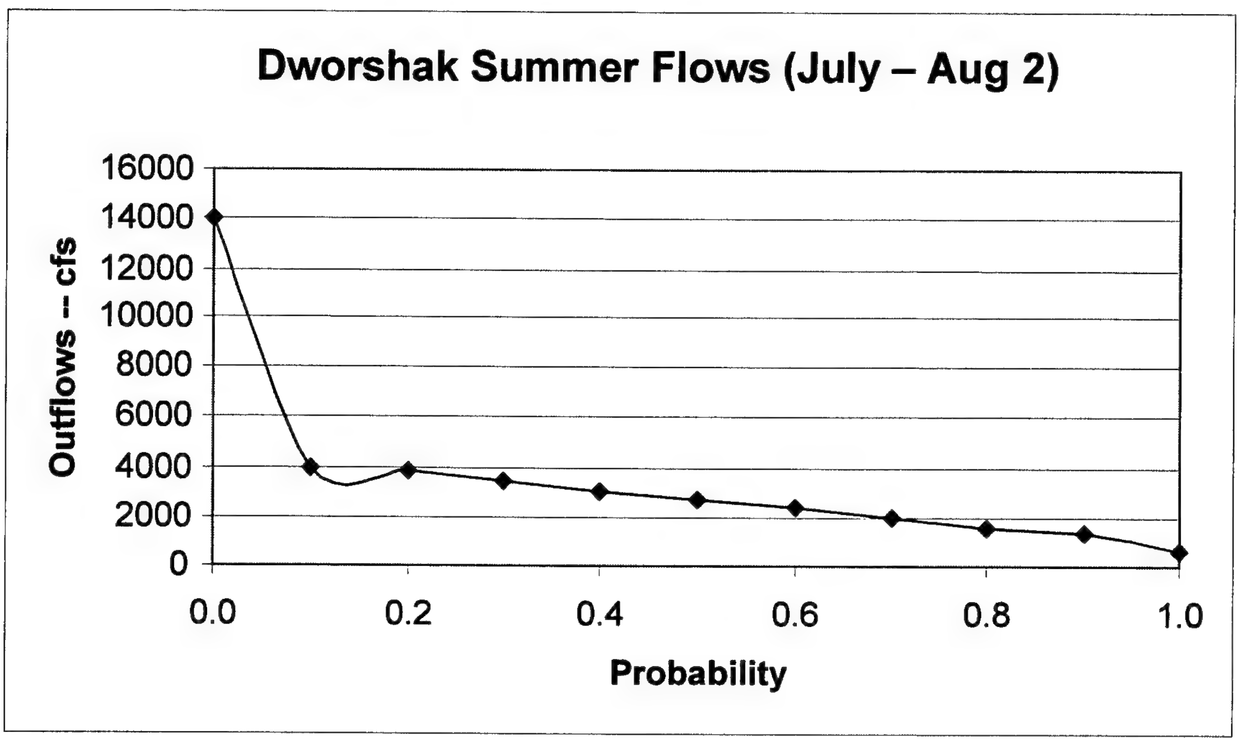


Figure B-4 Alternative A5 Graphs (continued)

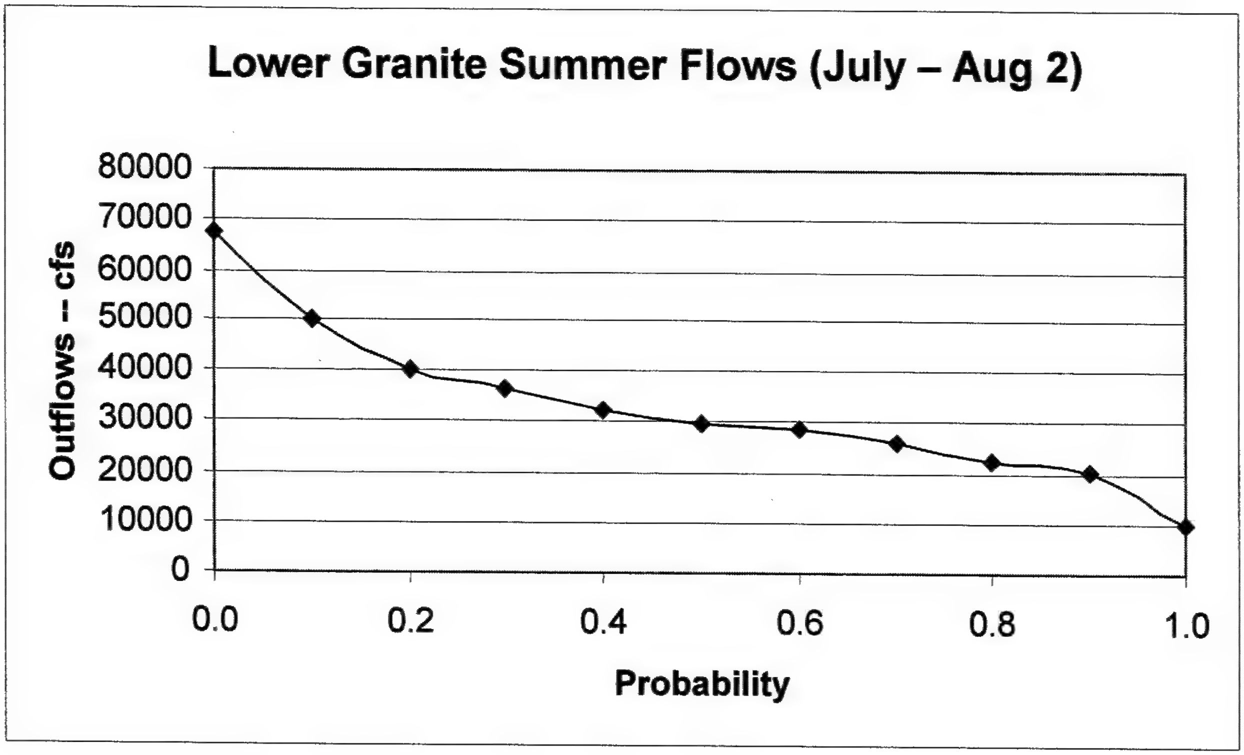
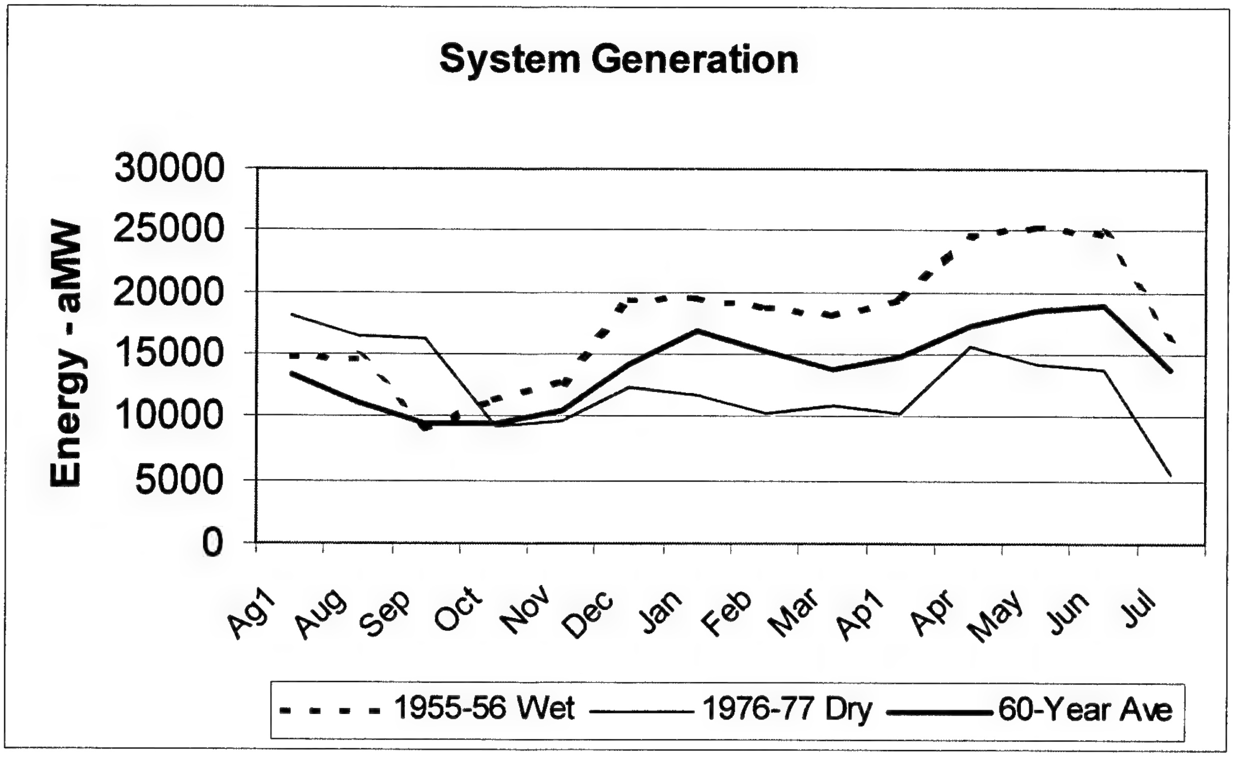


Figure B-5 Alternative A6a Graphs



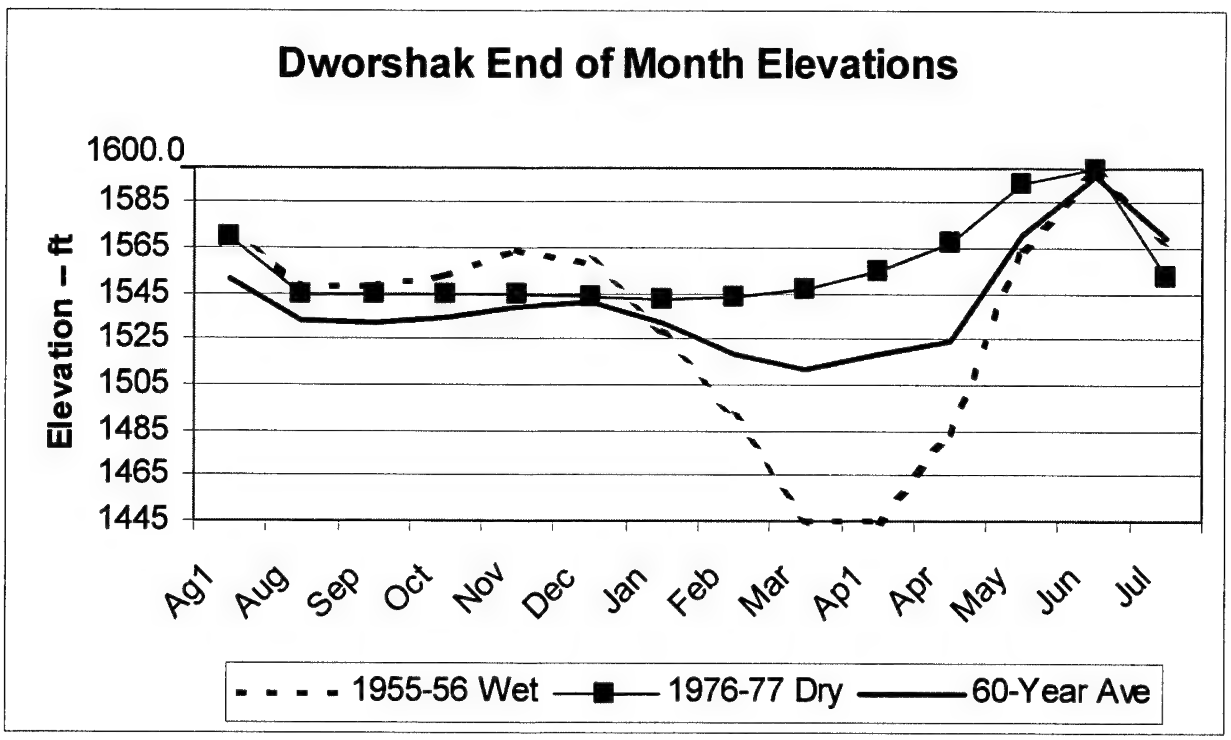
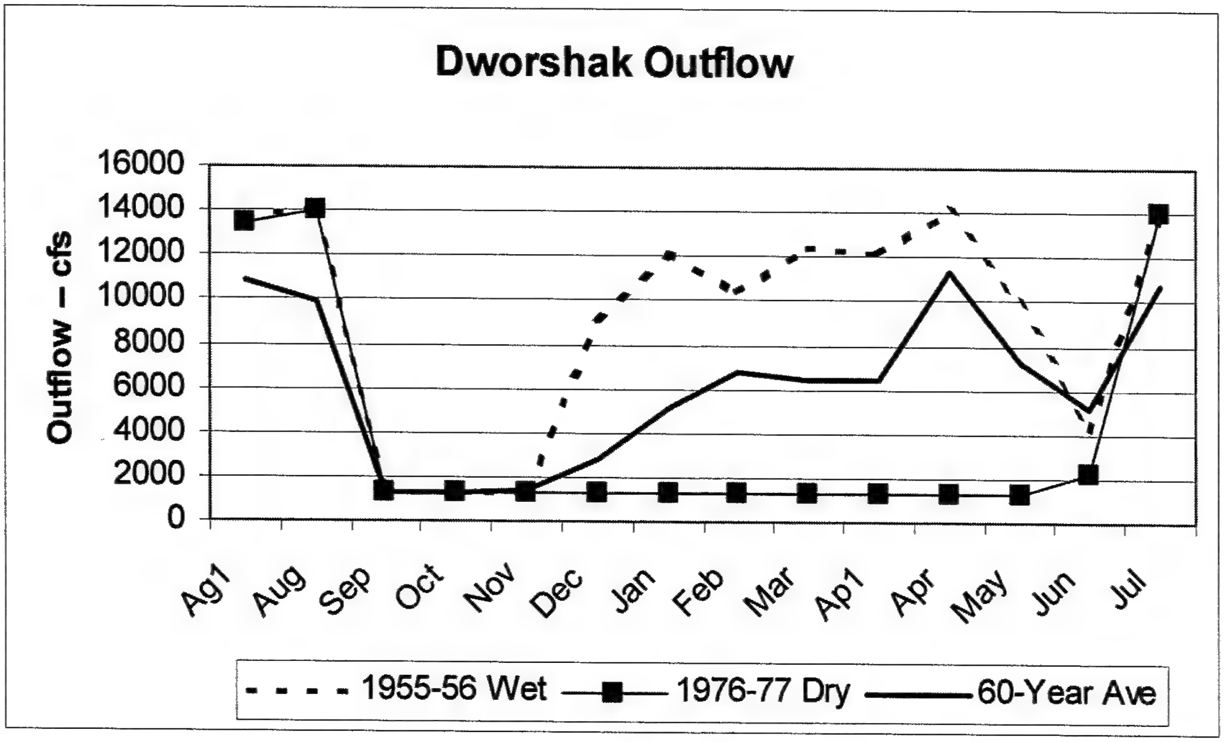


Figure B-5 Alternative A6a Graphs (continued)



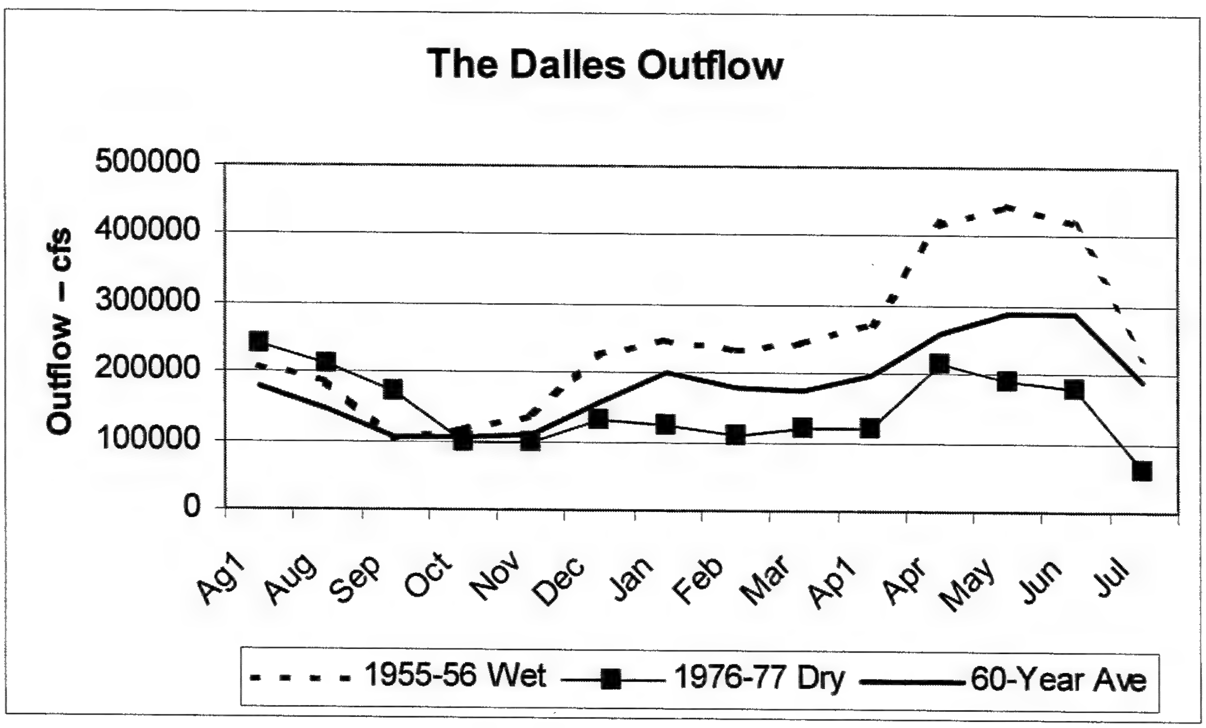
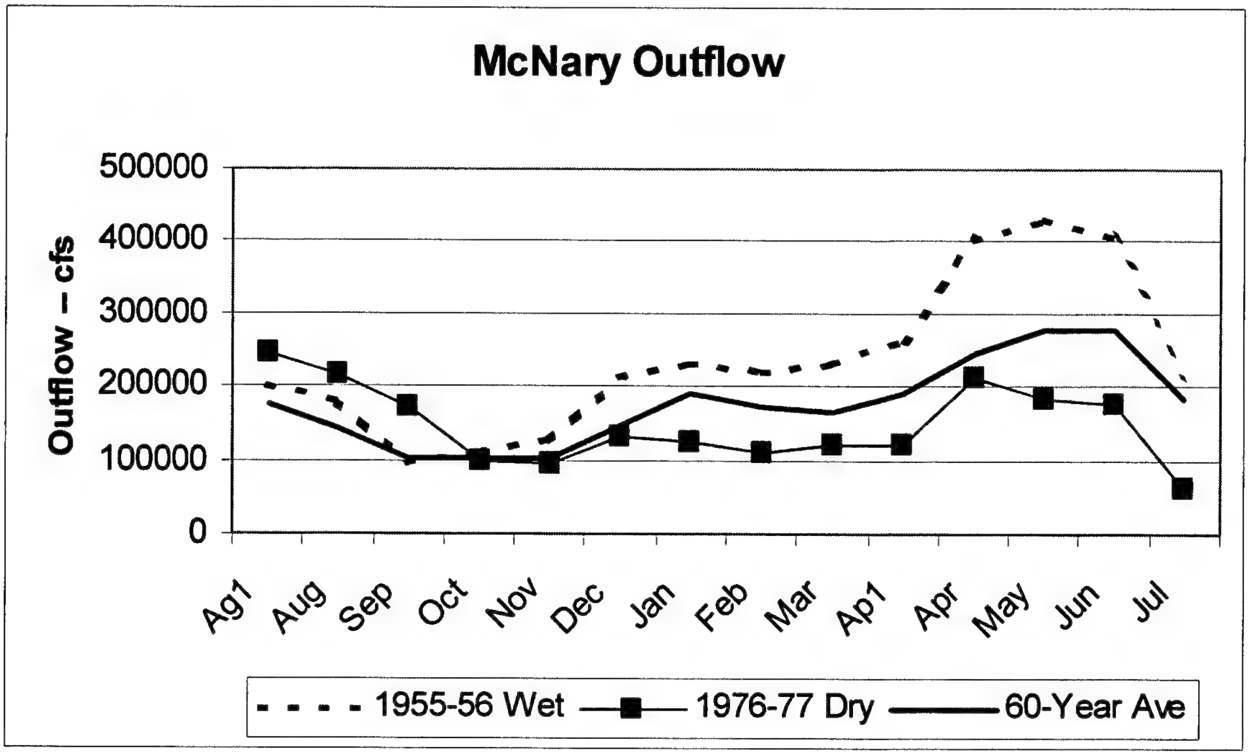


Figure B-5 Alternative A6a Graphs (continued)



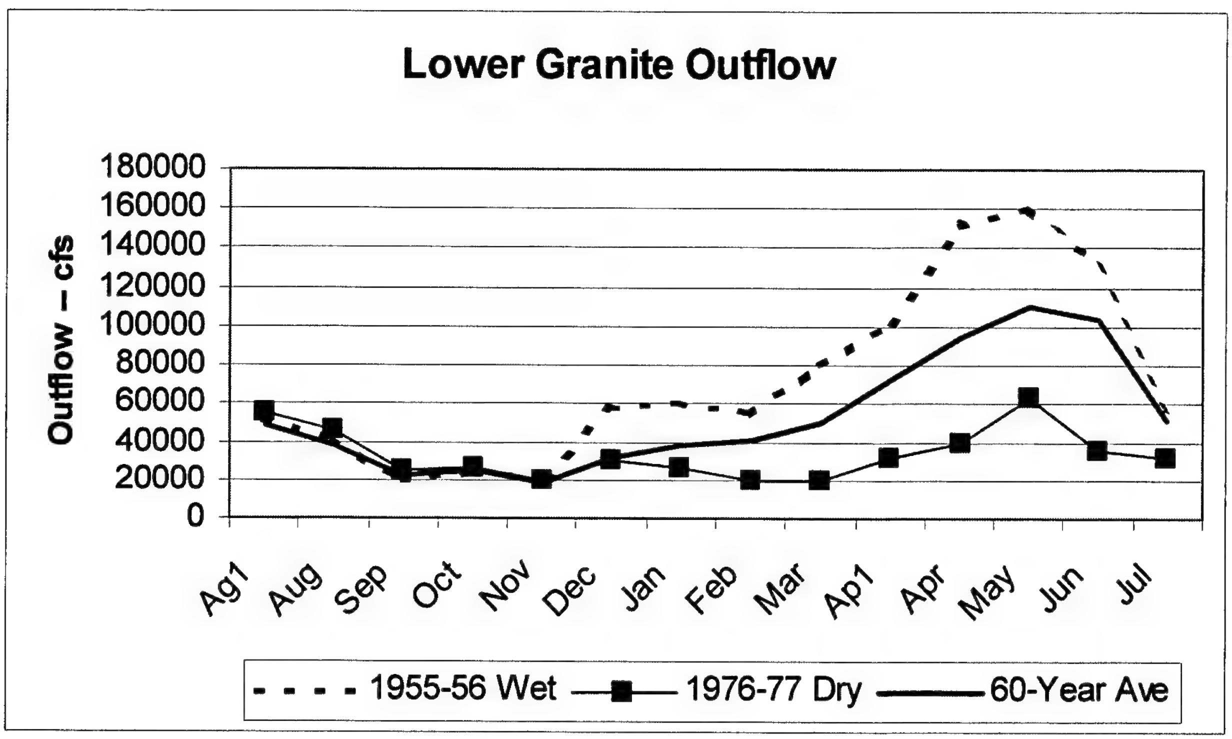
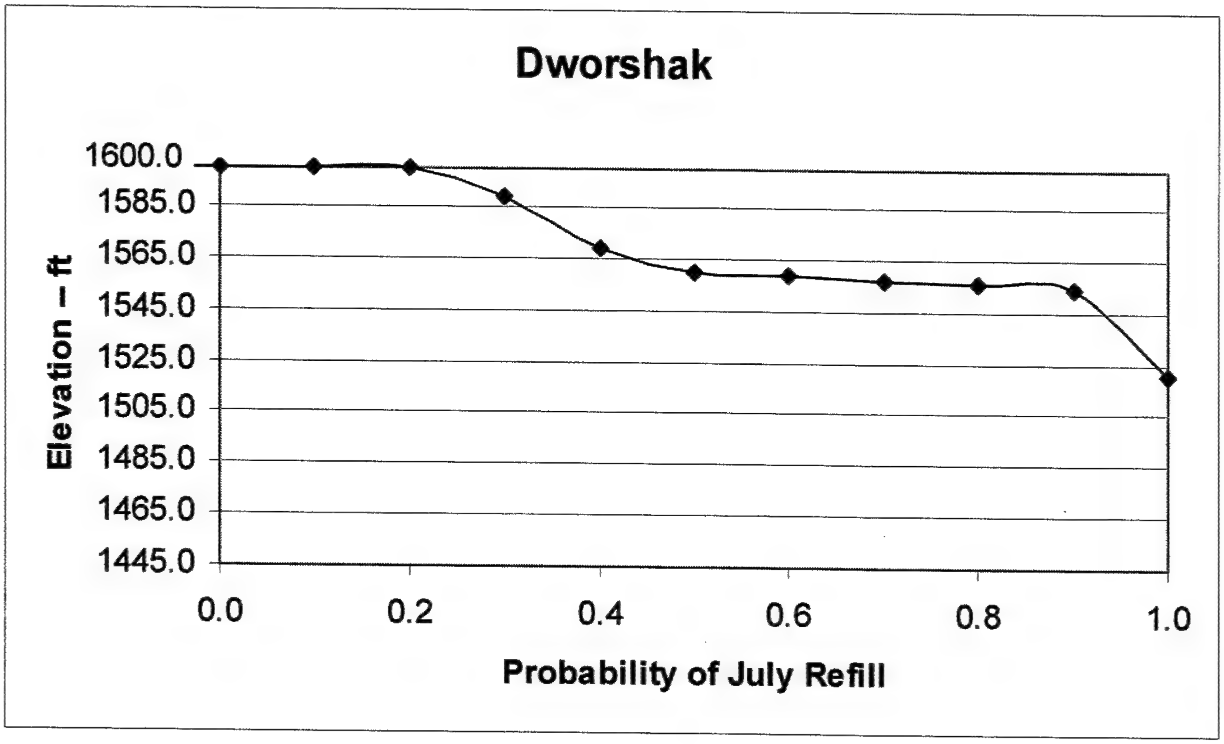


Figure B-5 Alternative A6a Graphs (continued)



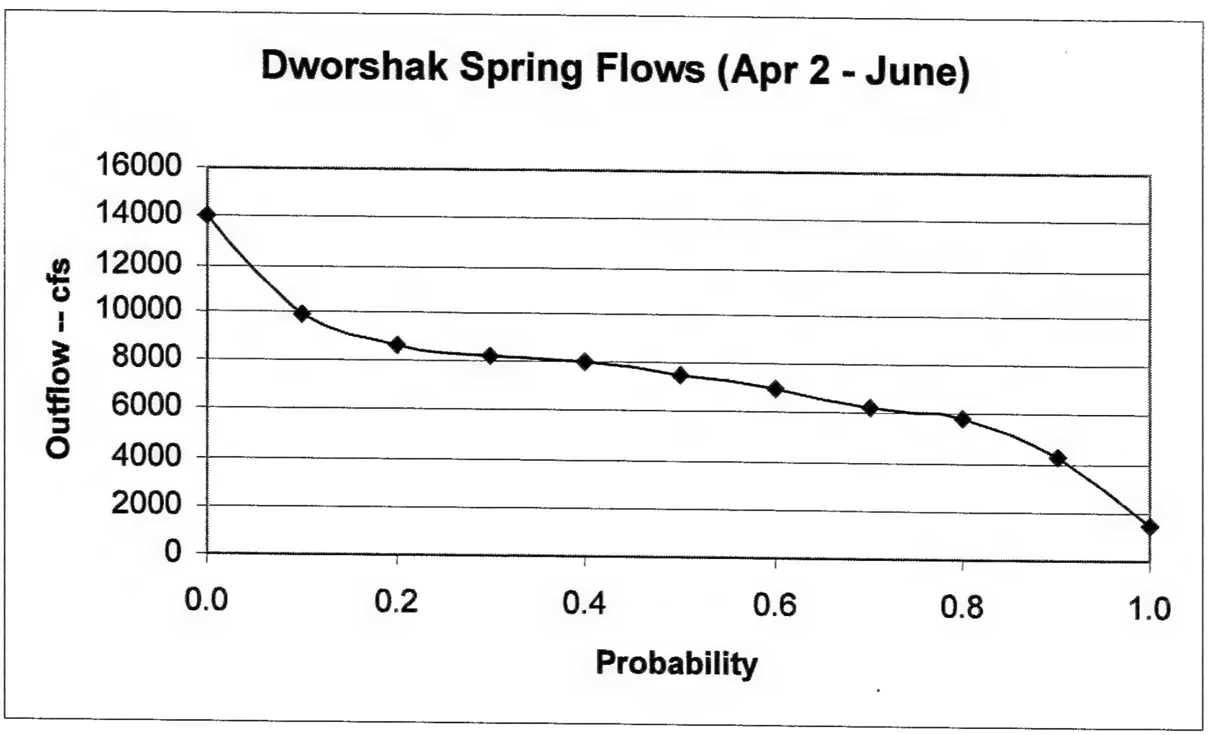
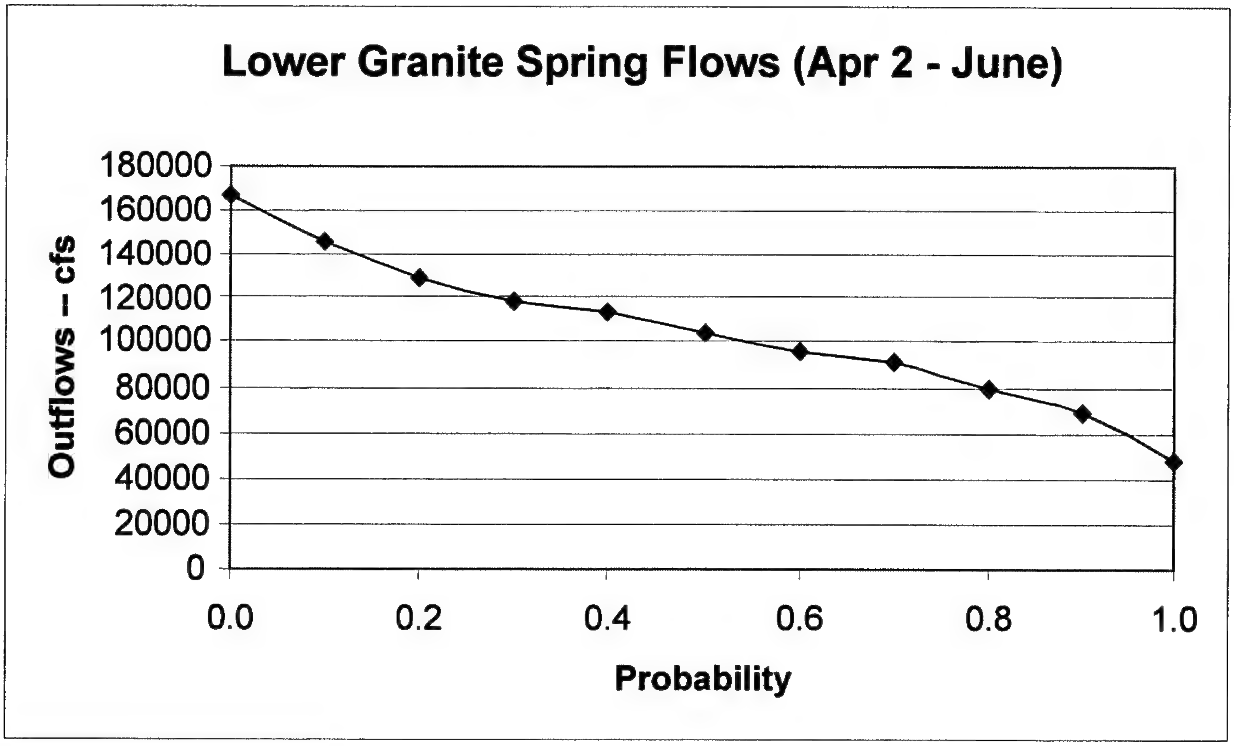


Figure B-5 Alternative A6a Graphs (continued)



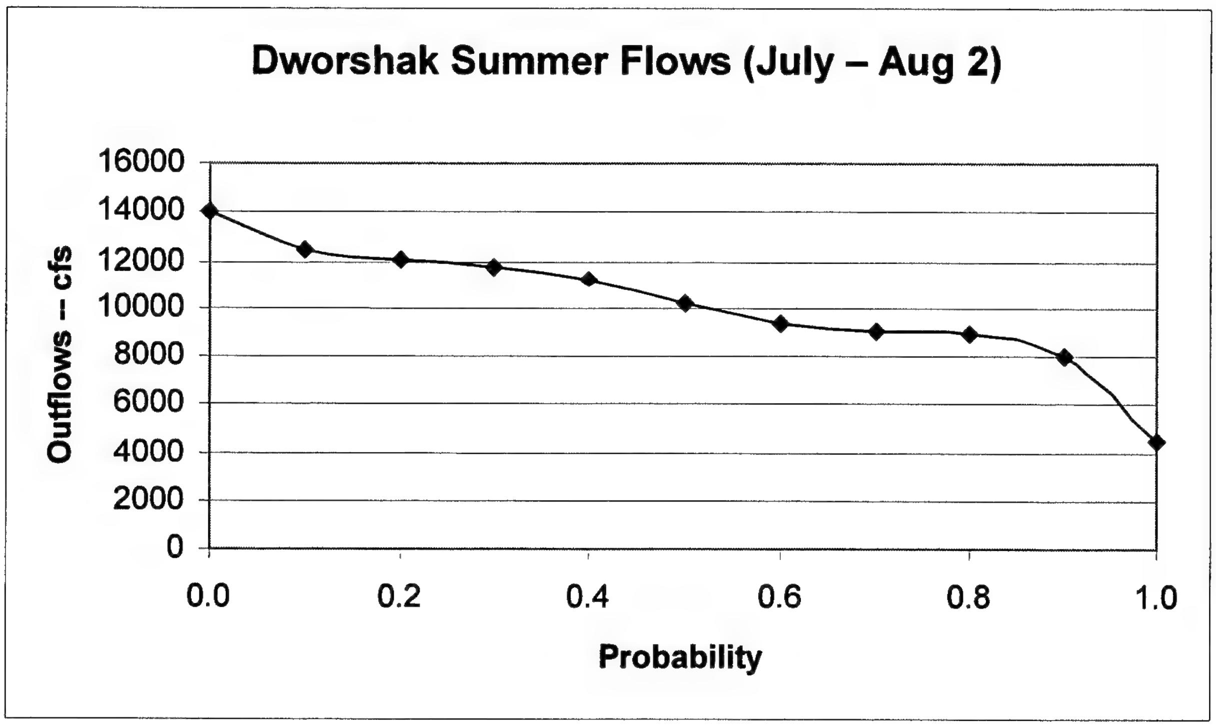


Figure B-5 Alternative A6a Graphs (continued)

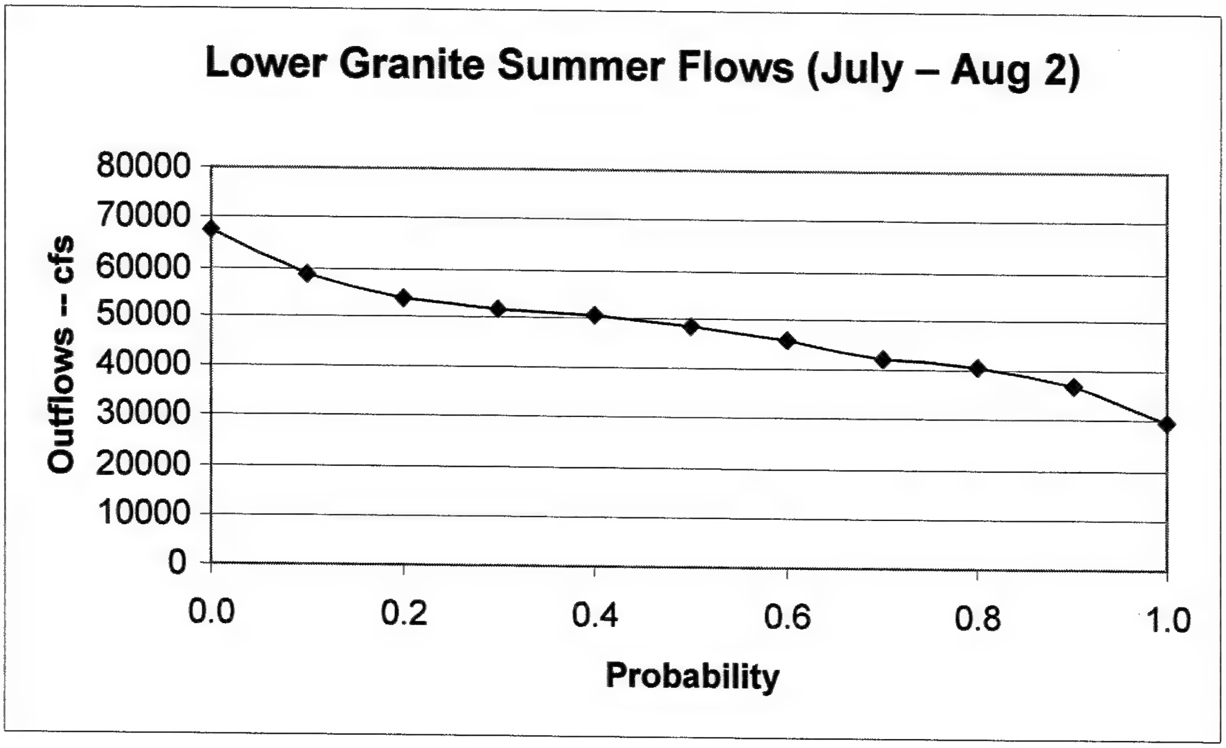
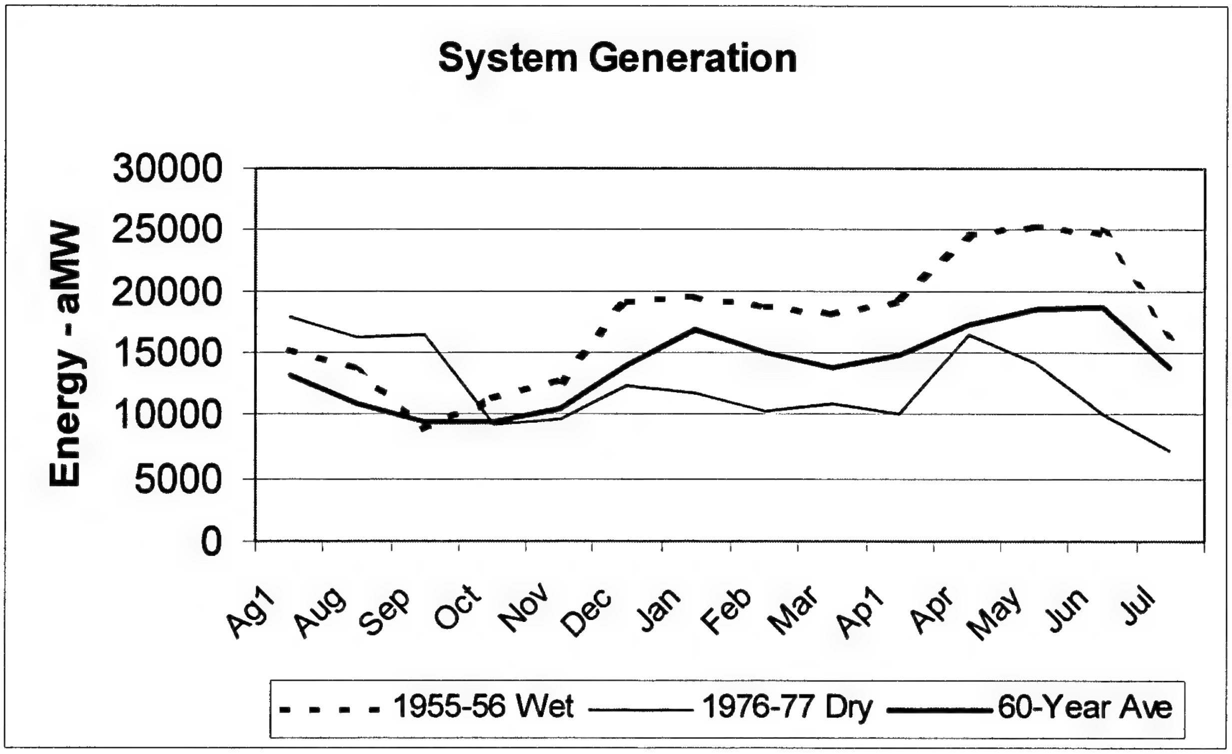


Figure B-6 Alternative A6b Graphs



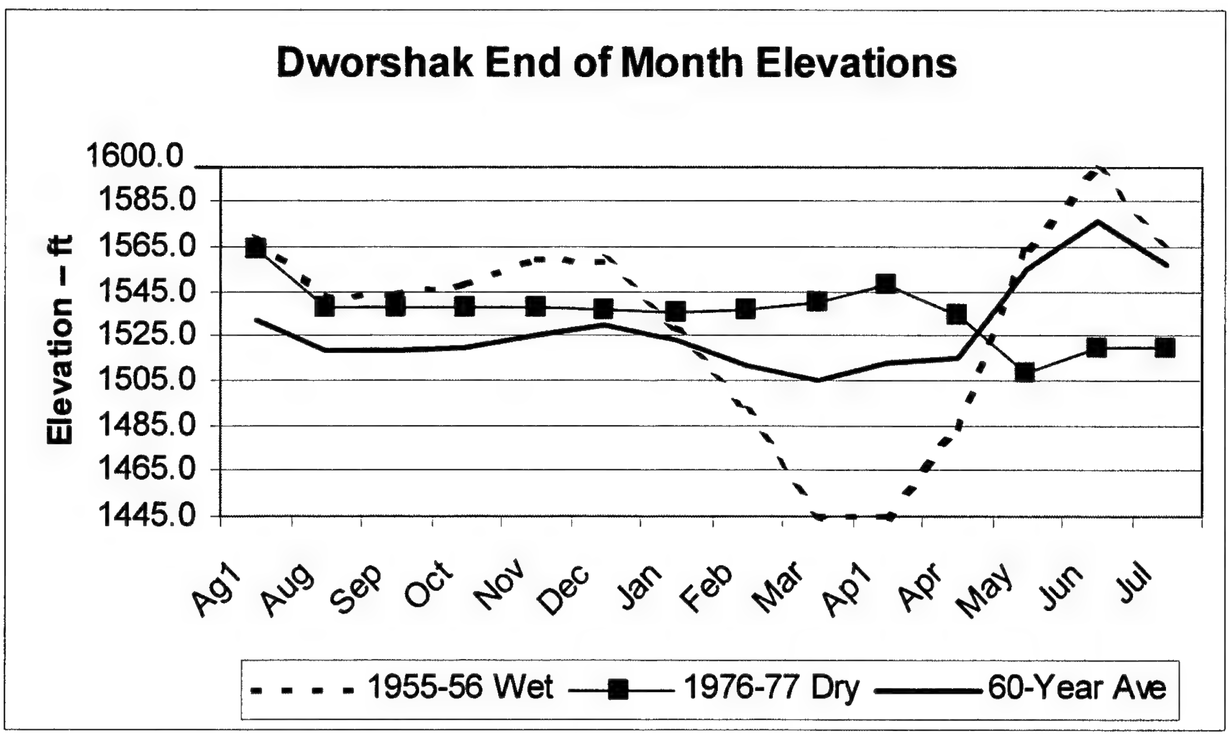
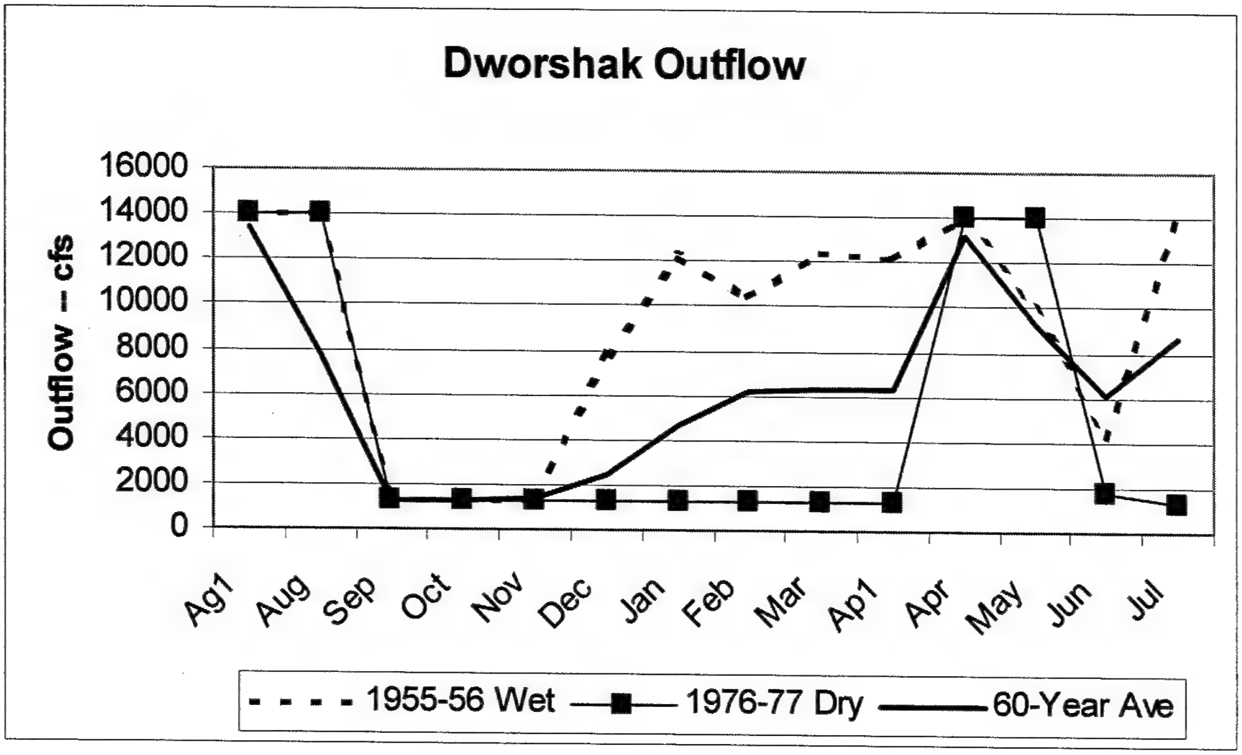


Figure B-6 Alternative A6b Graphs (continued)



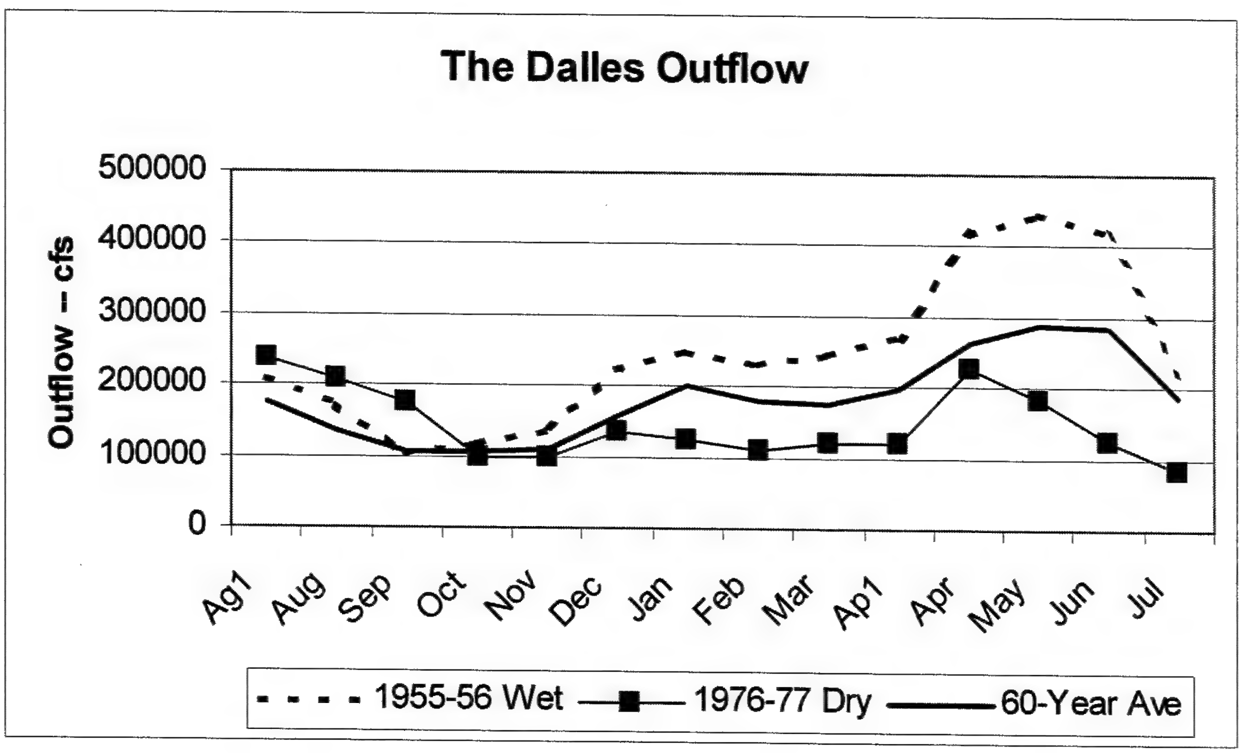
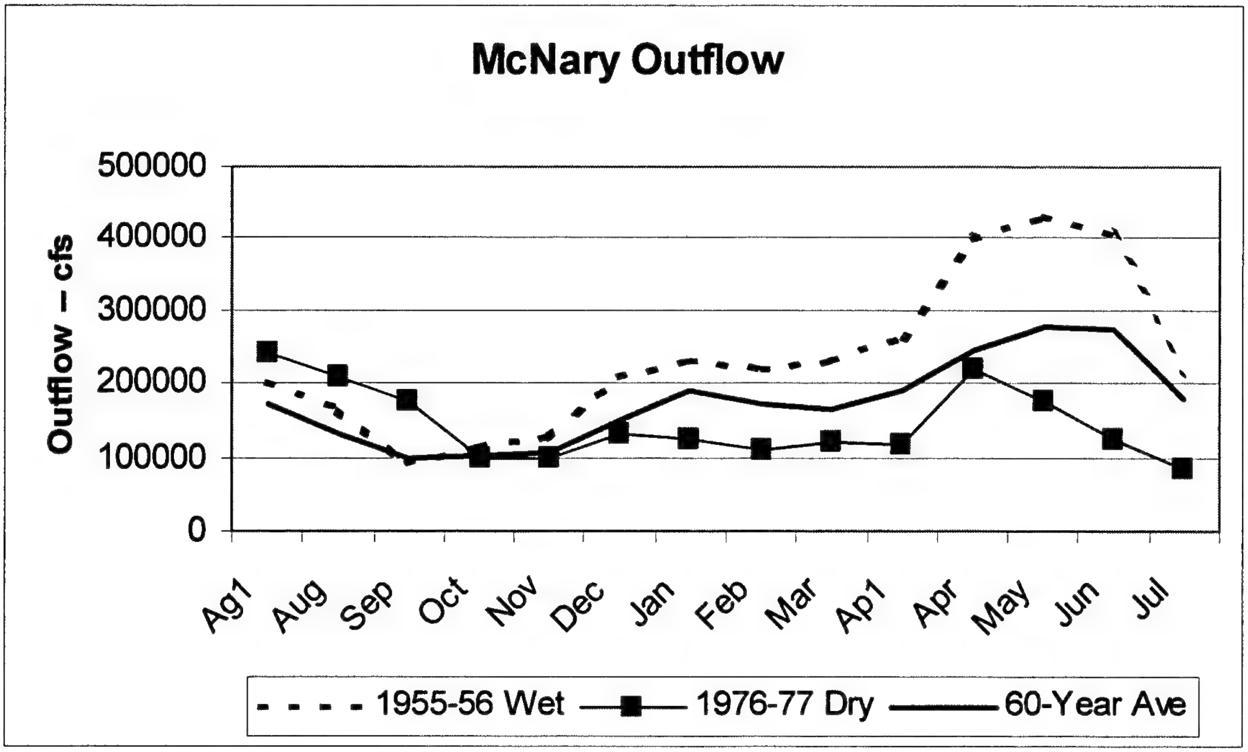


Figure B-6 Alternative A6b Graphs (continued)



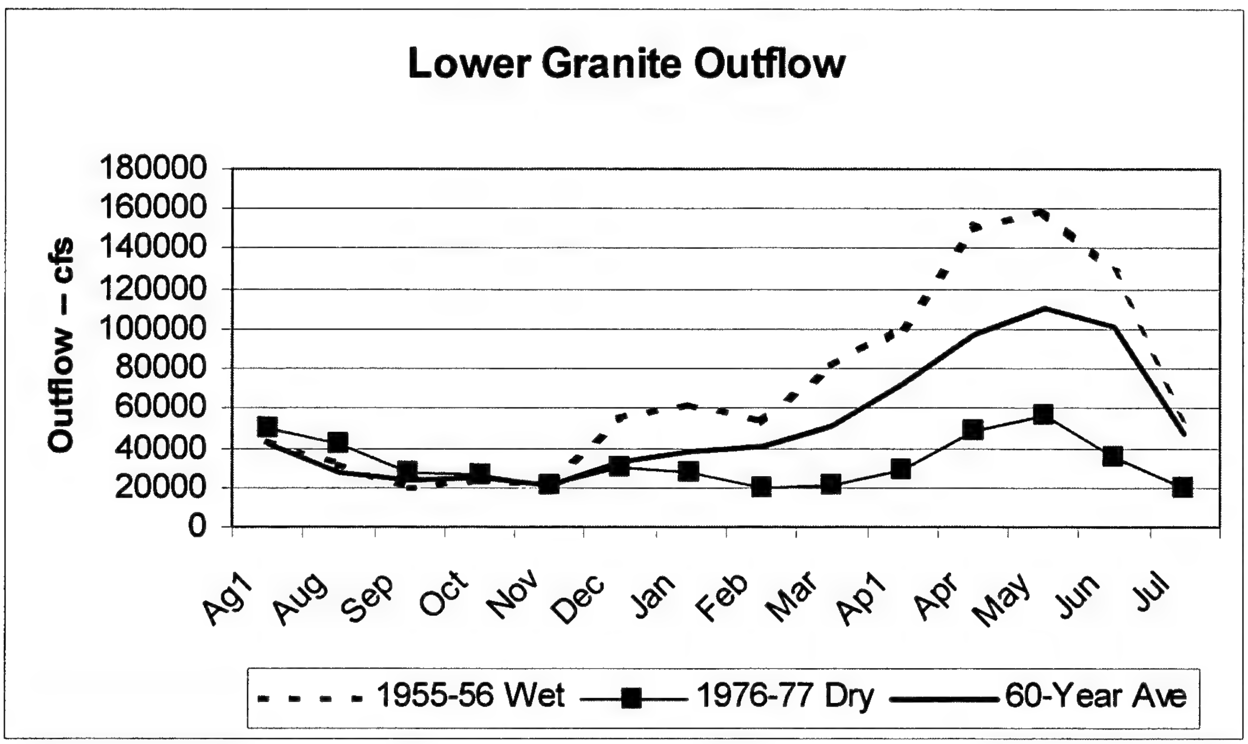
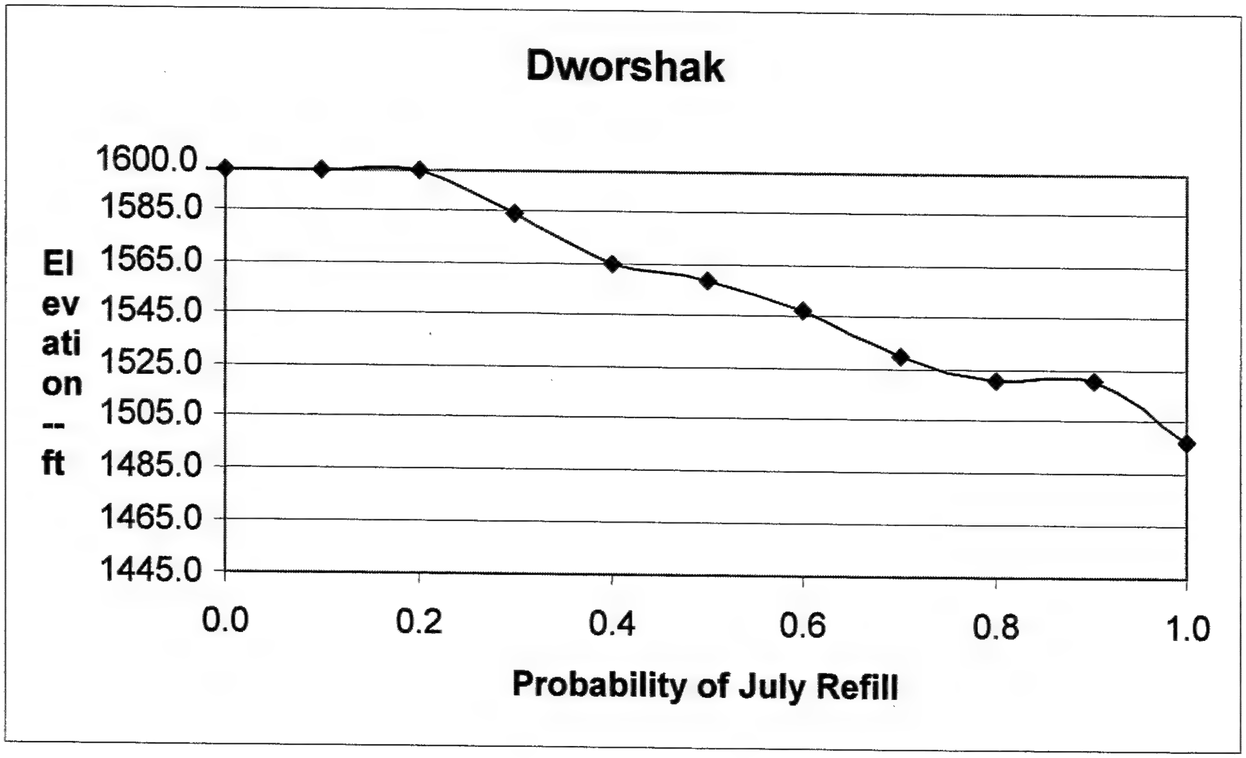


Figure B-6 Alternative A6b Graphs (continued)



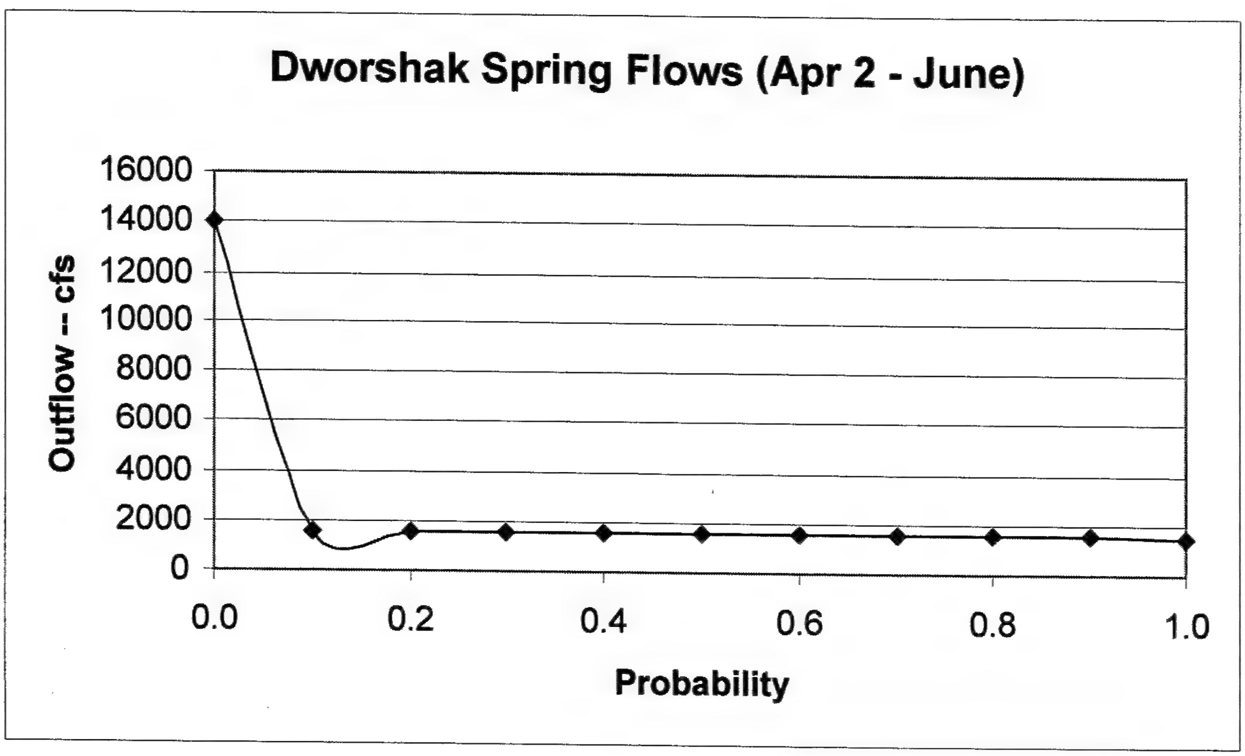
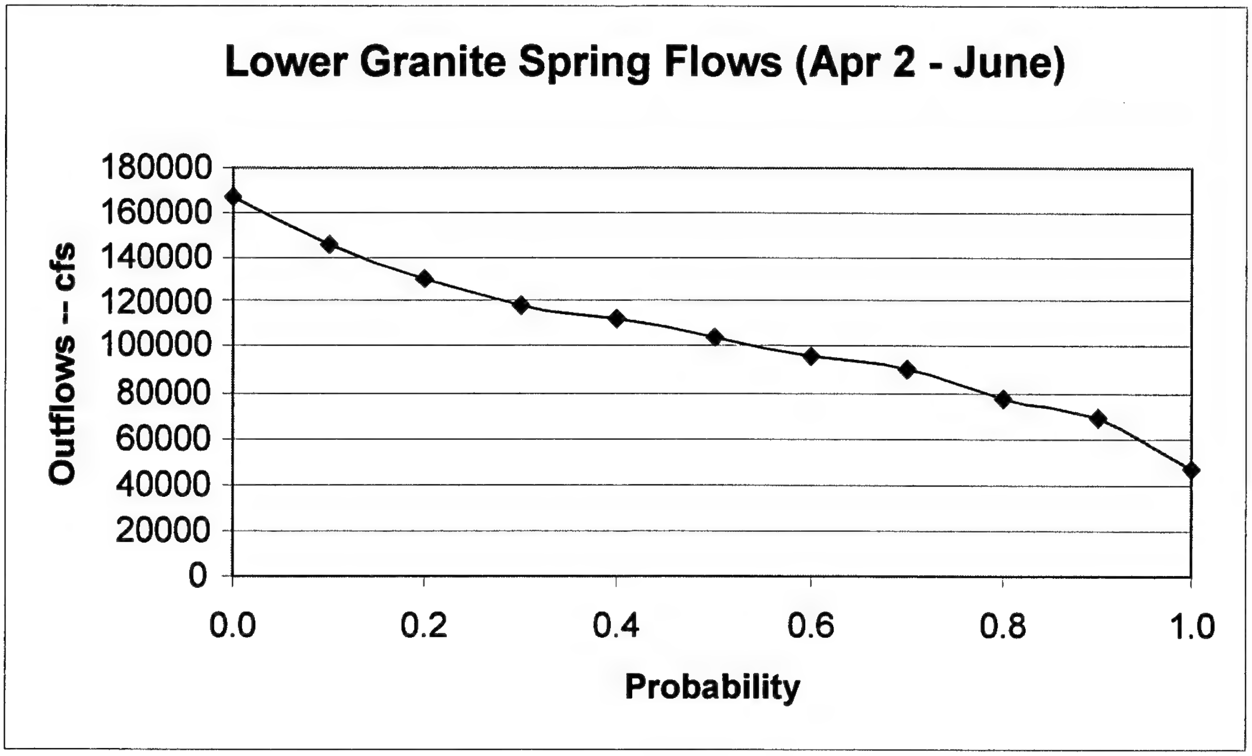


Figure B-6 Alternative A6b Graphs (continued)



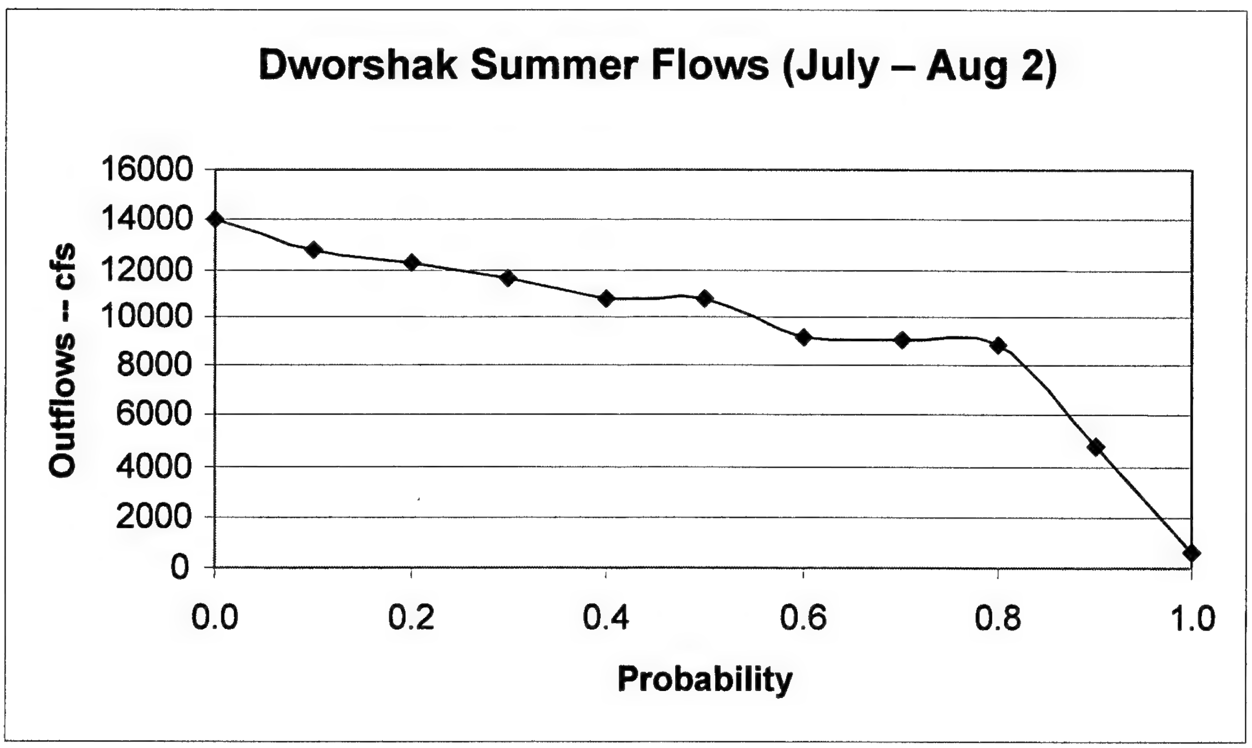


Figure B-6 Alternative A6b Graphs (continued)

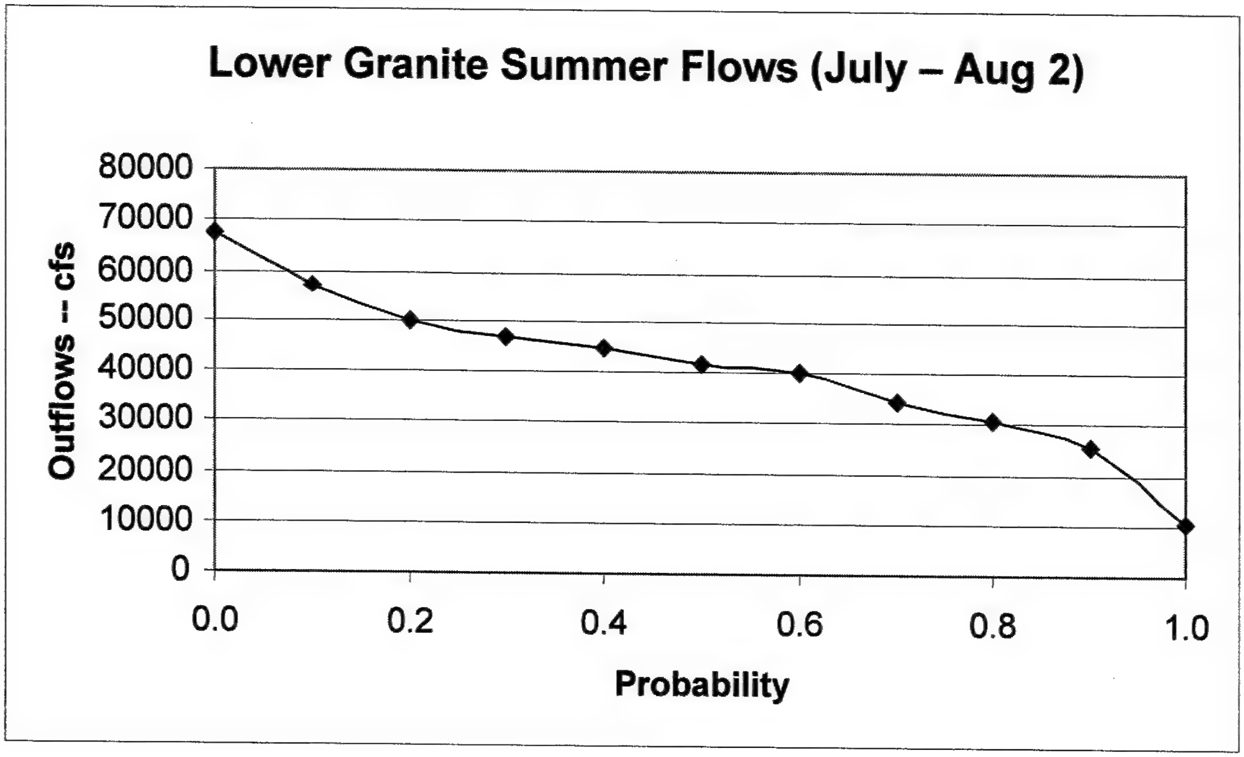
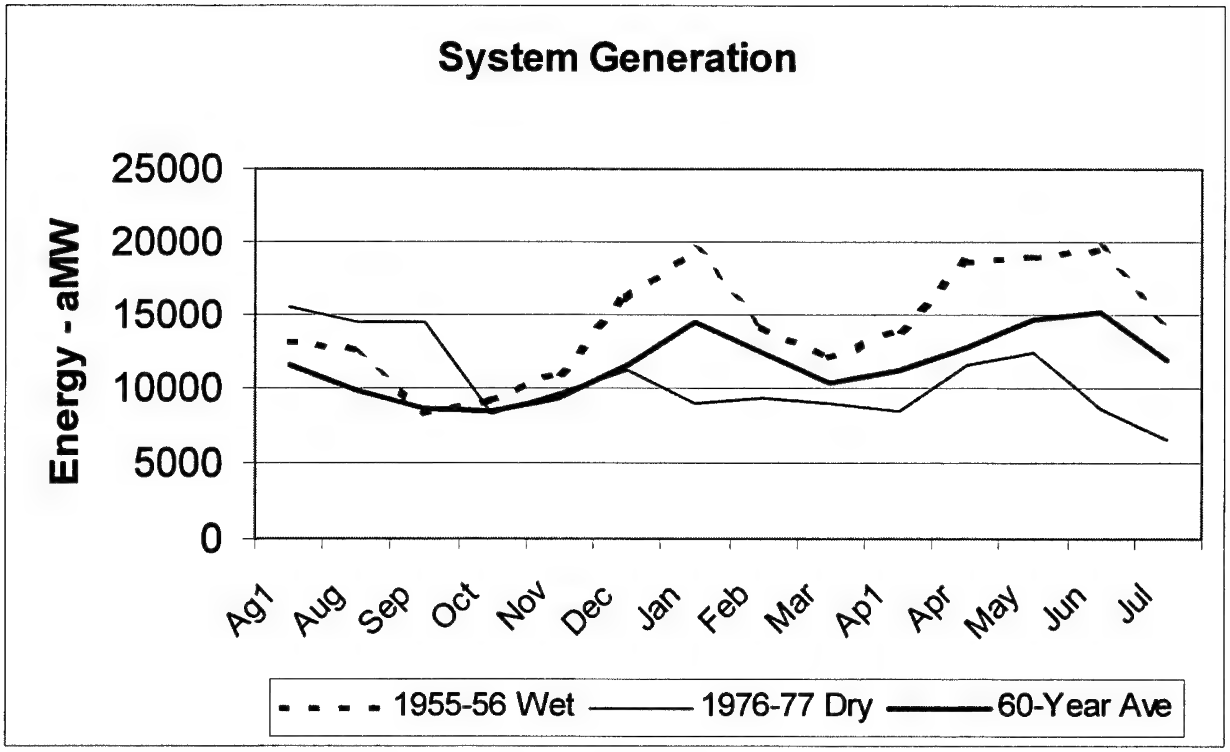


Figure B-7 Alternative B1 Graphs



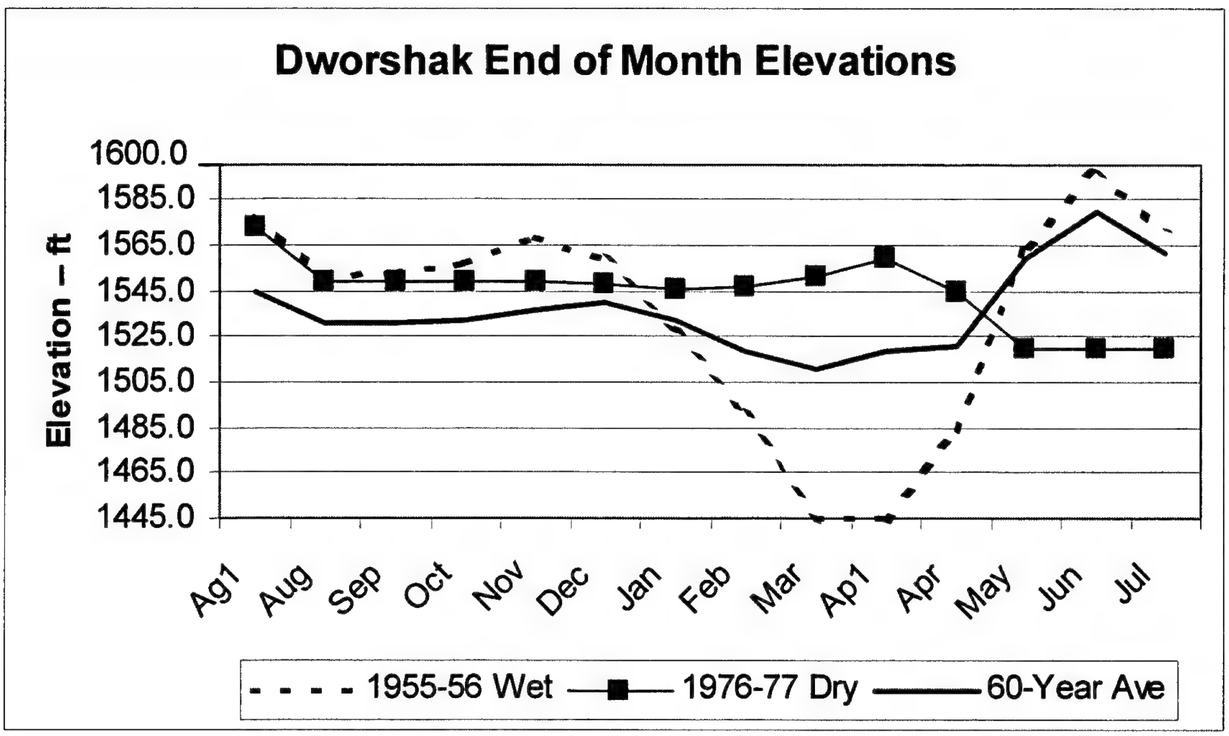
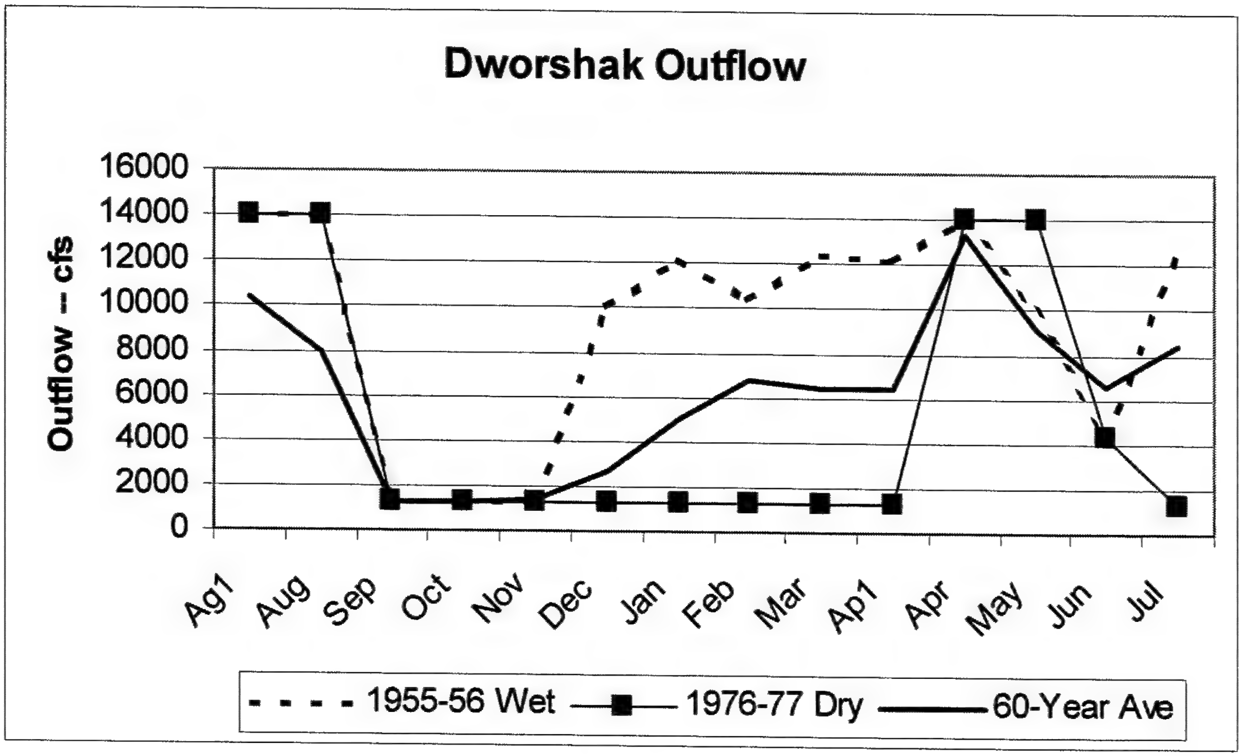


Figure B-7 Alternative B1 Graphs (continued)



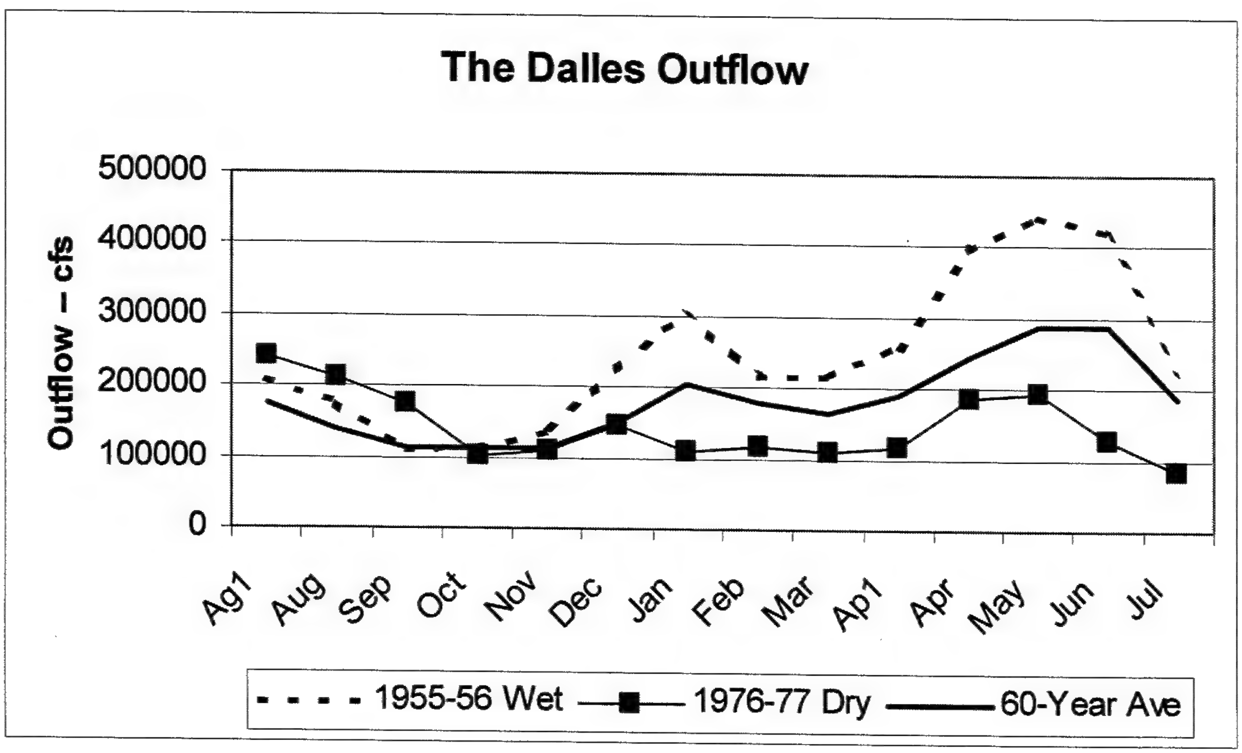
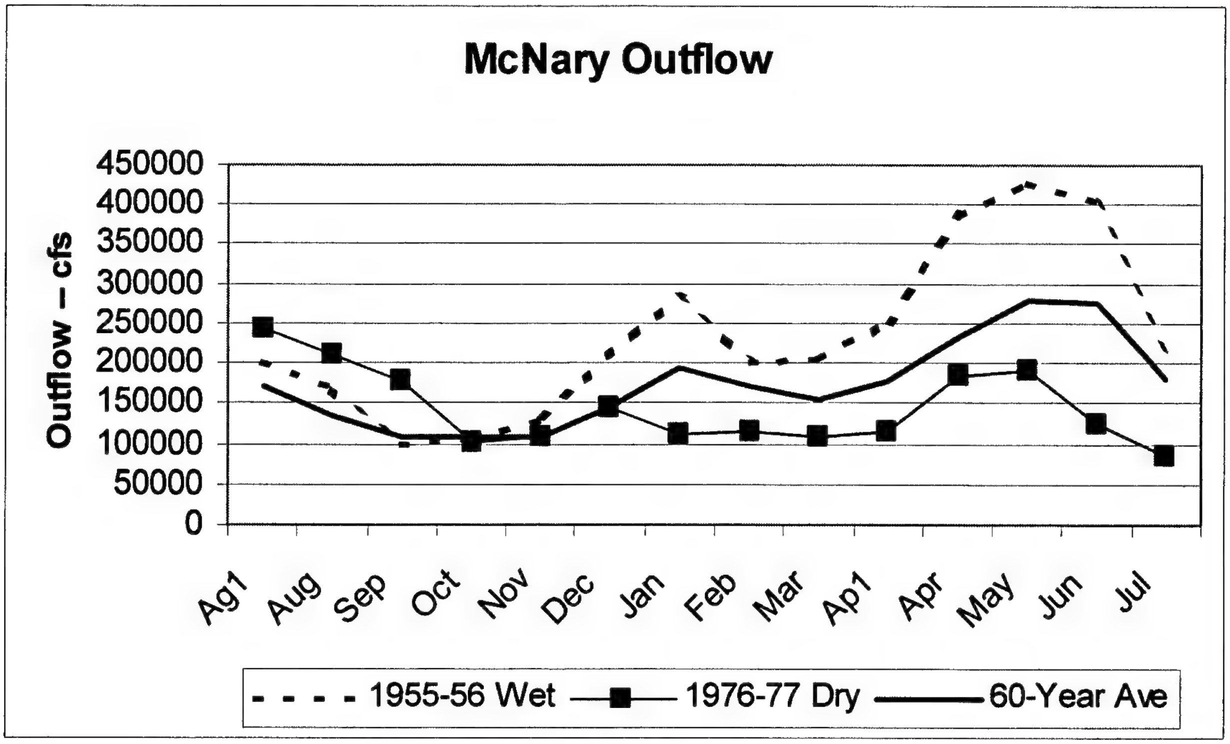


Figure B-7 Alternative B1 Graphs (continued)



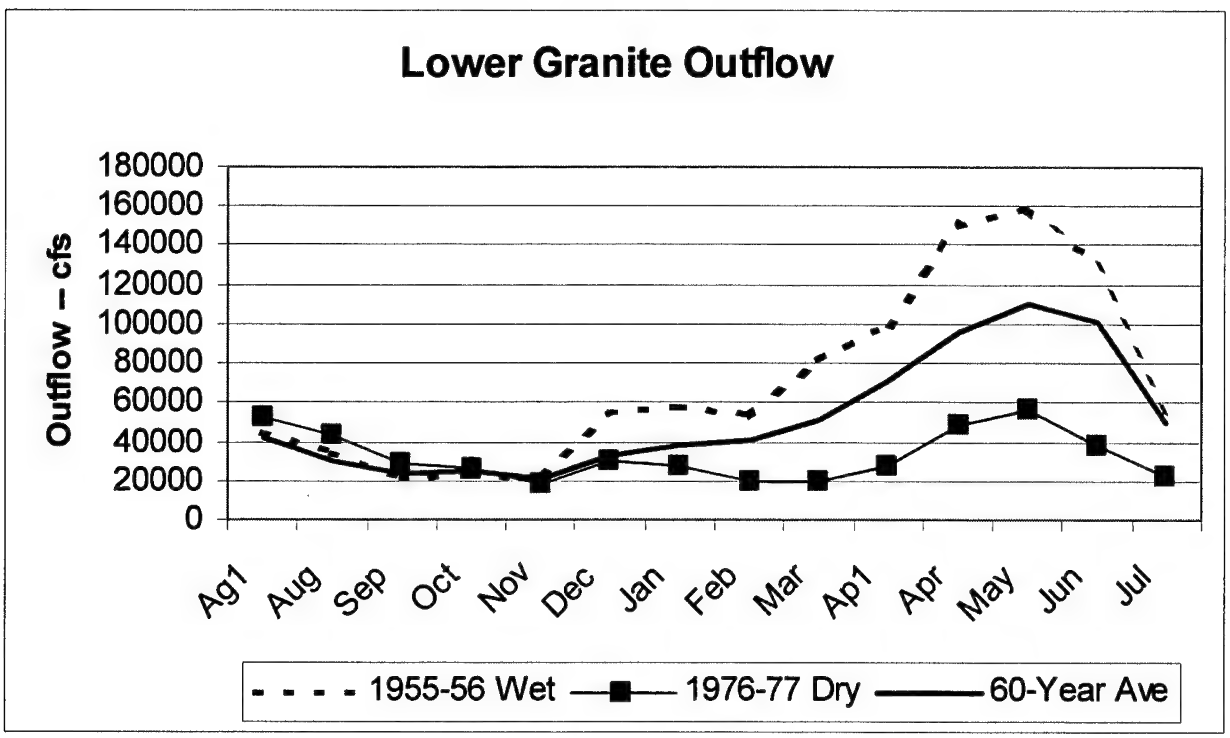
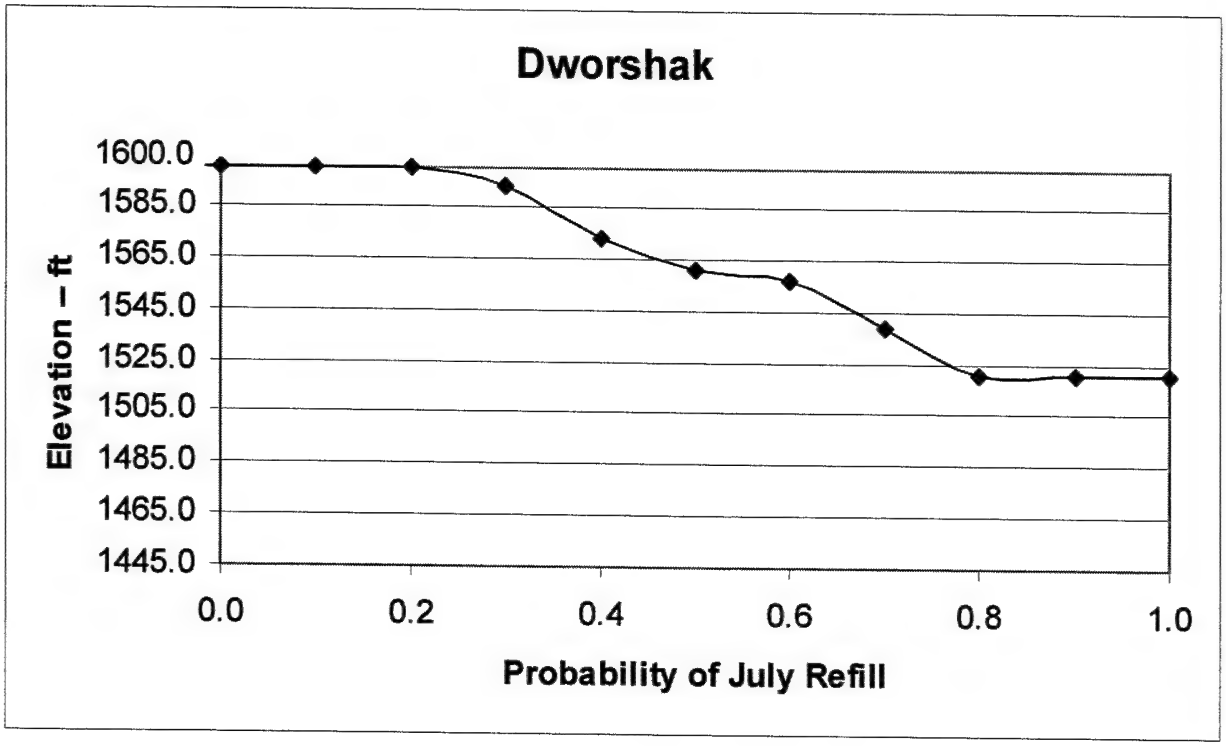


Figure B-7 Alternative B1 Graphs (continued)



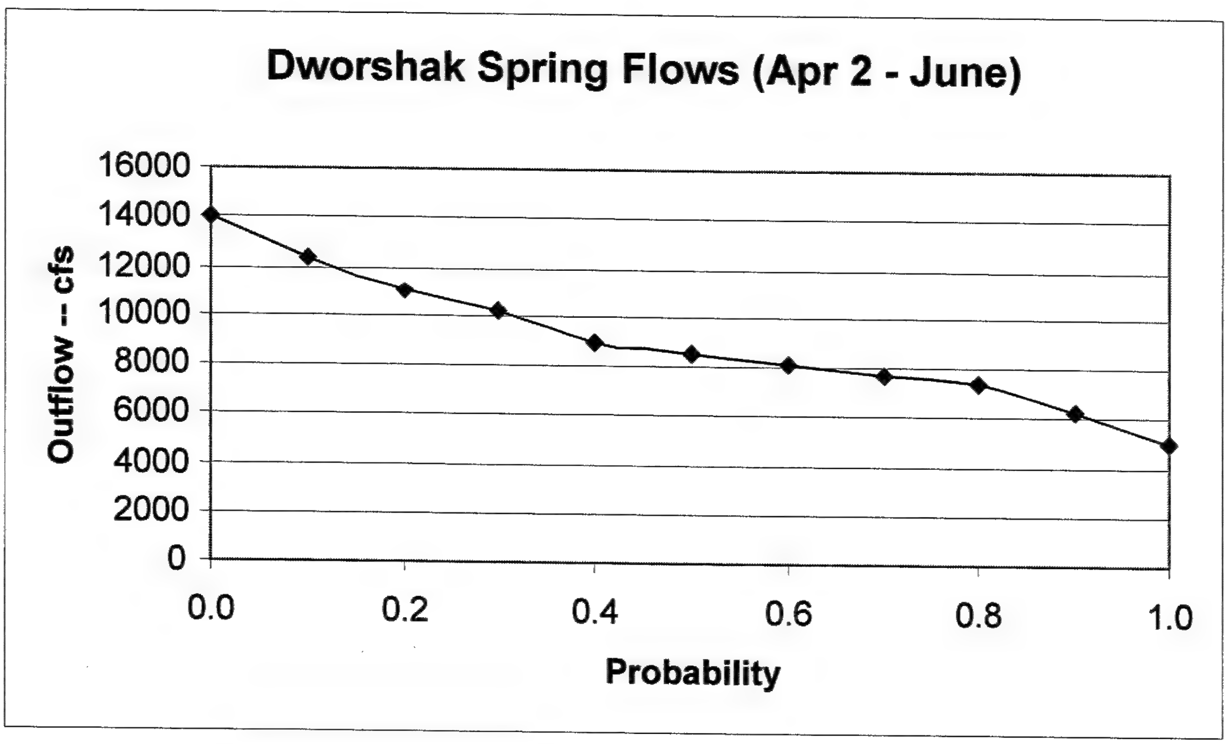
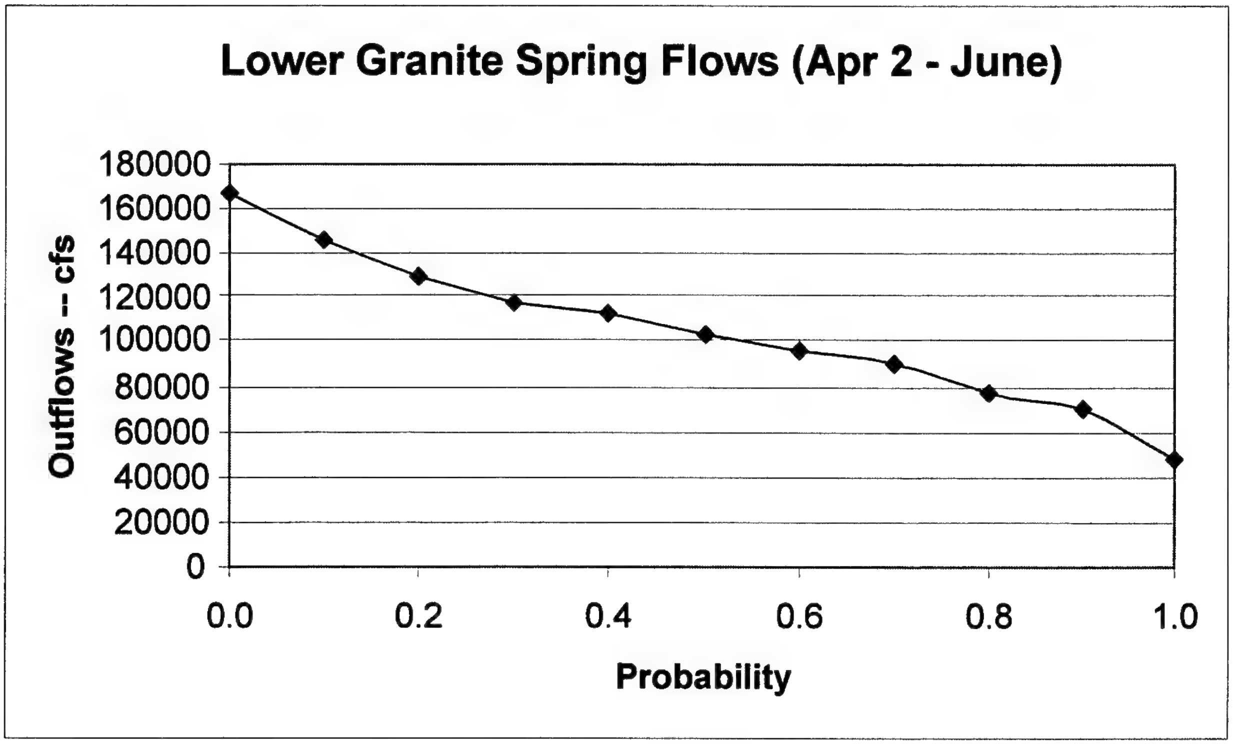


Figure B-7 Alternative B1 Graphs (continued)



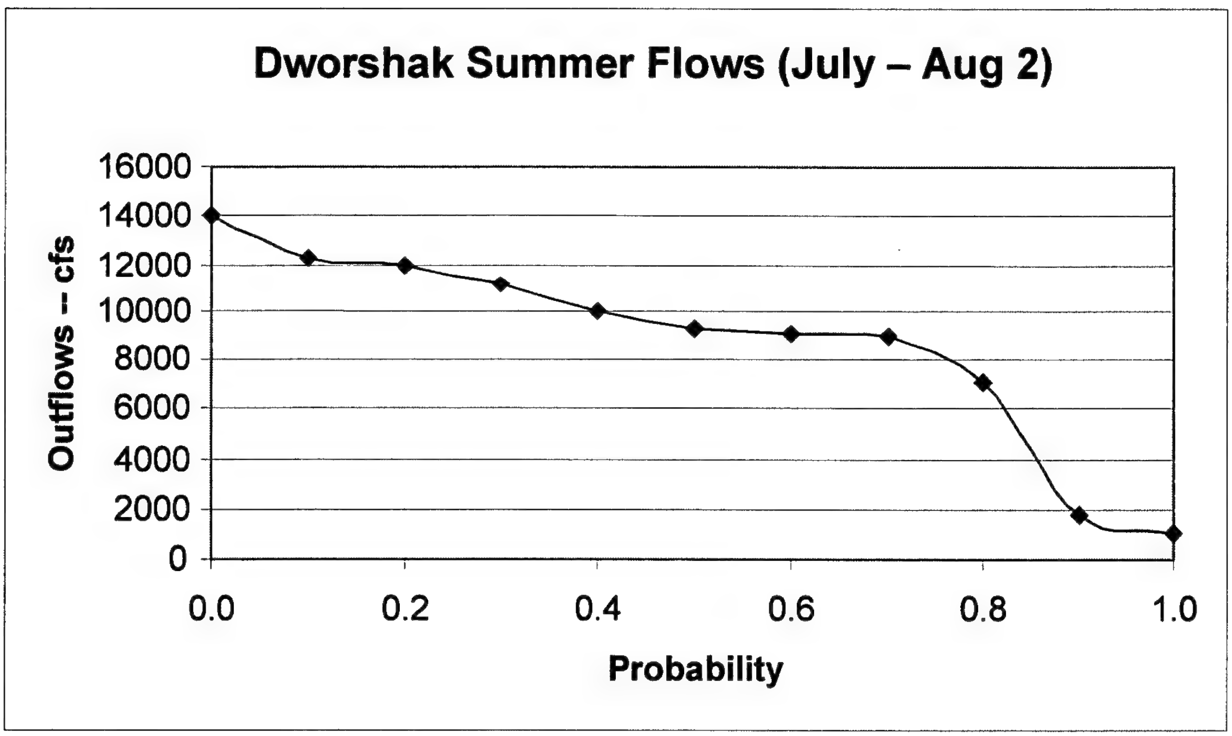


Figure B-7 Alternative B1 Graphs (continued)

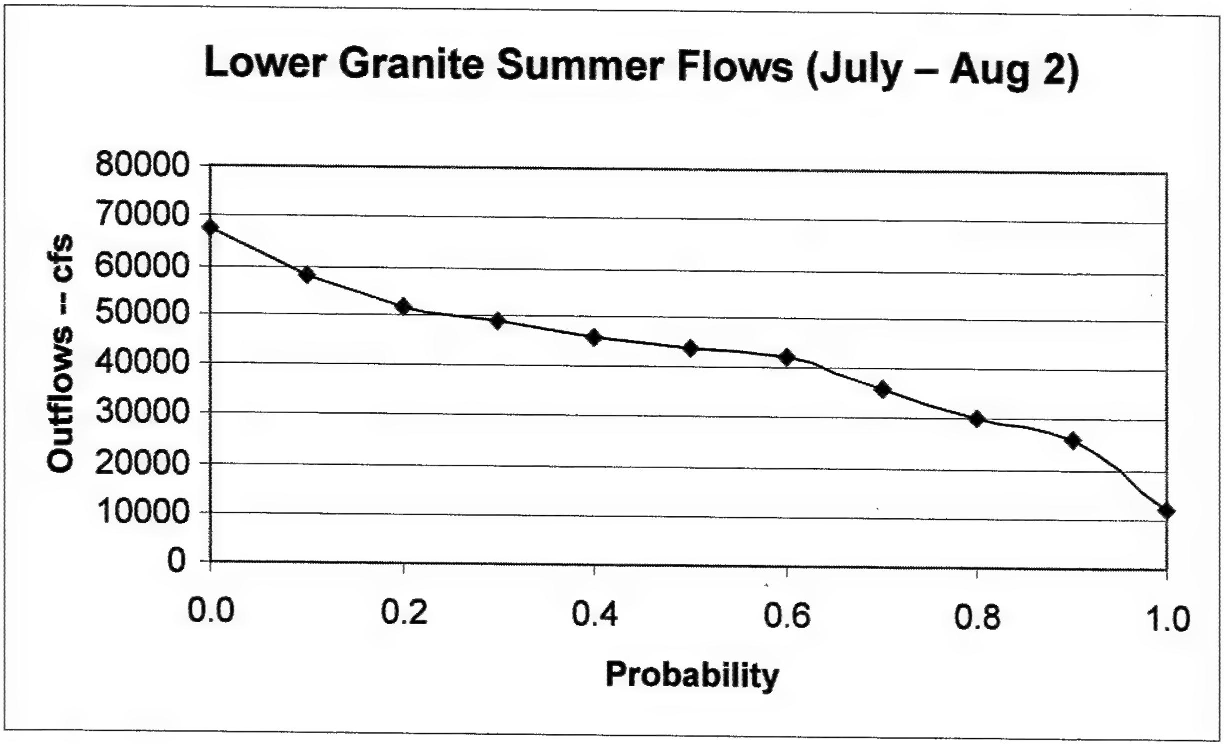
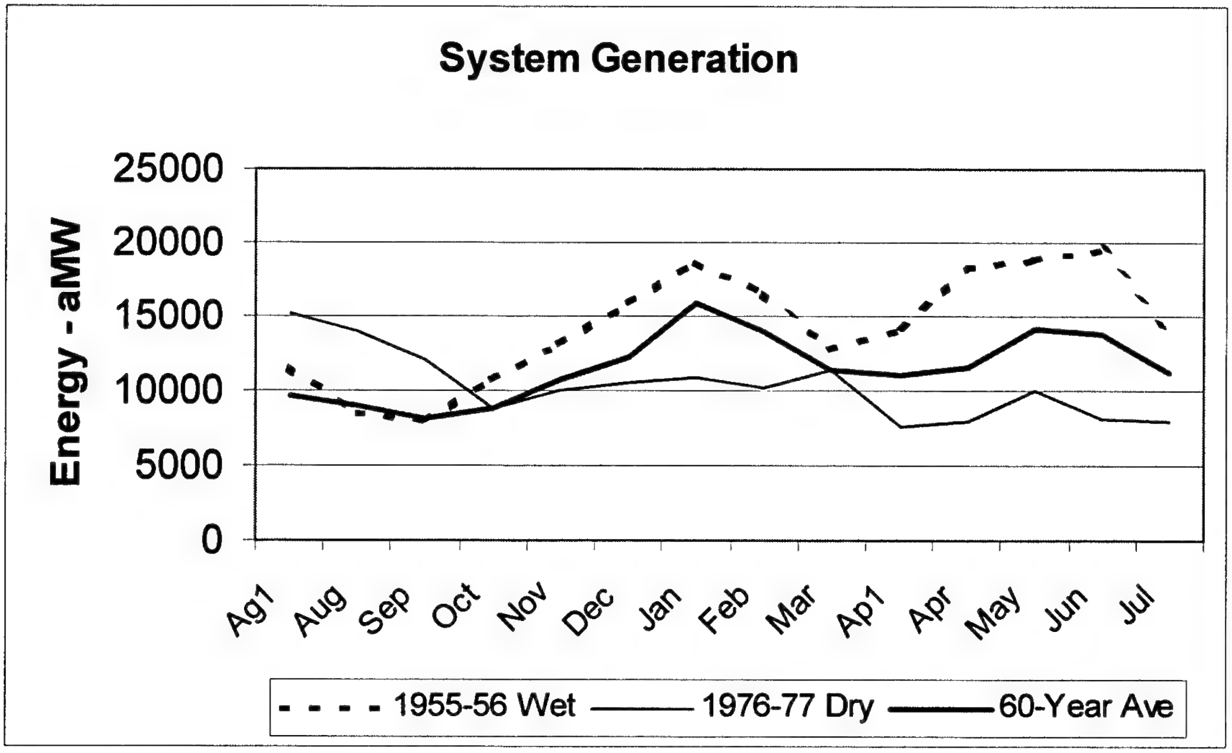


Figure B-8 Alternative B2 Graphs



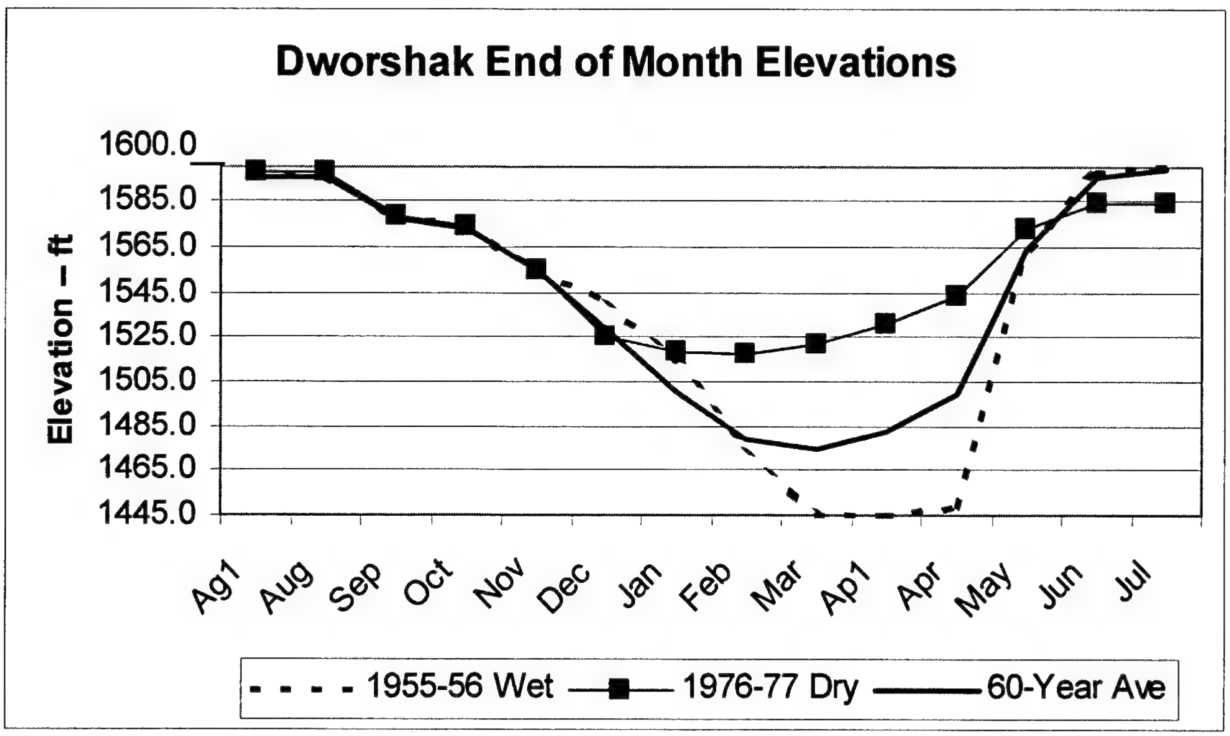
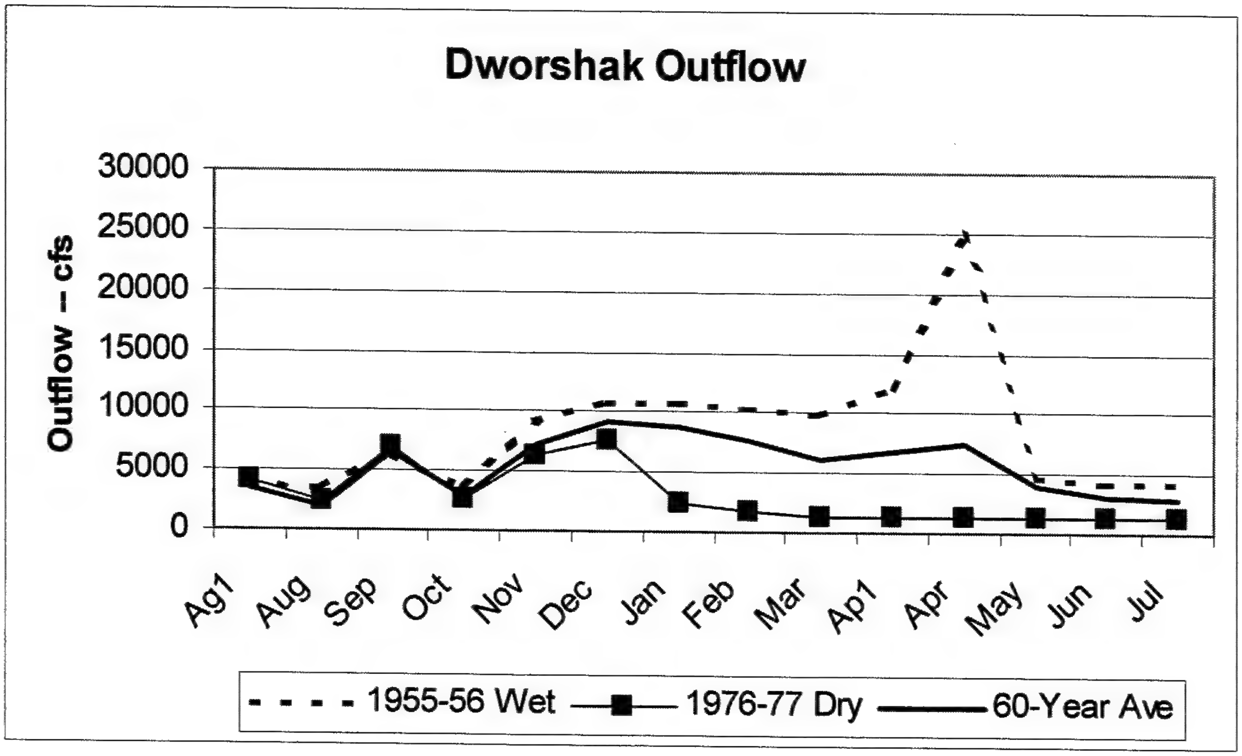


Figure B-8 Alternative B2 Graphs (continued)



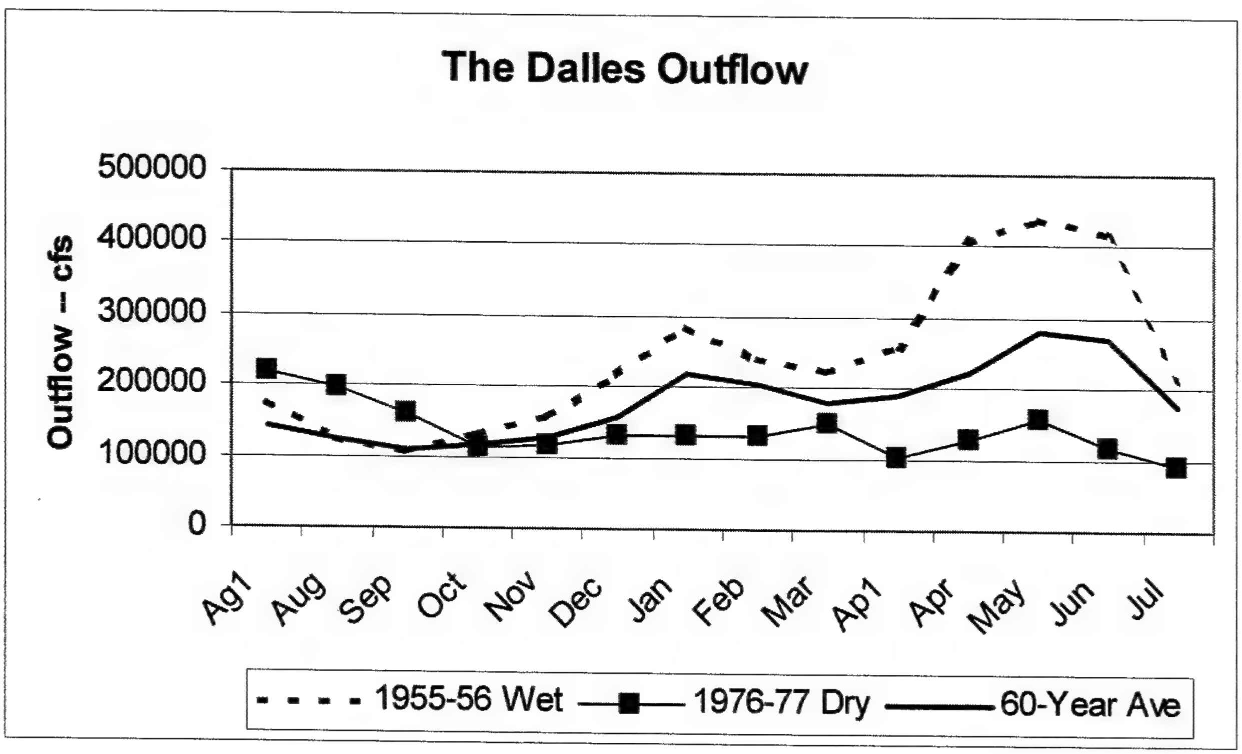
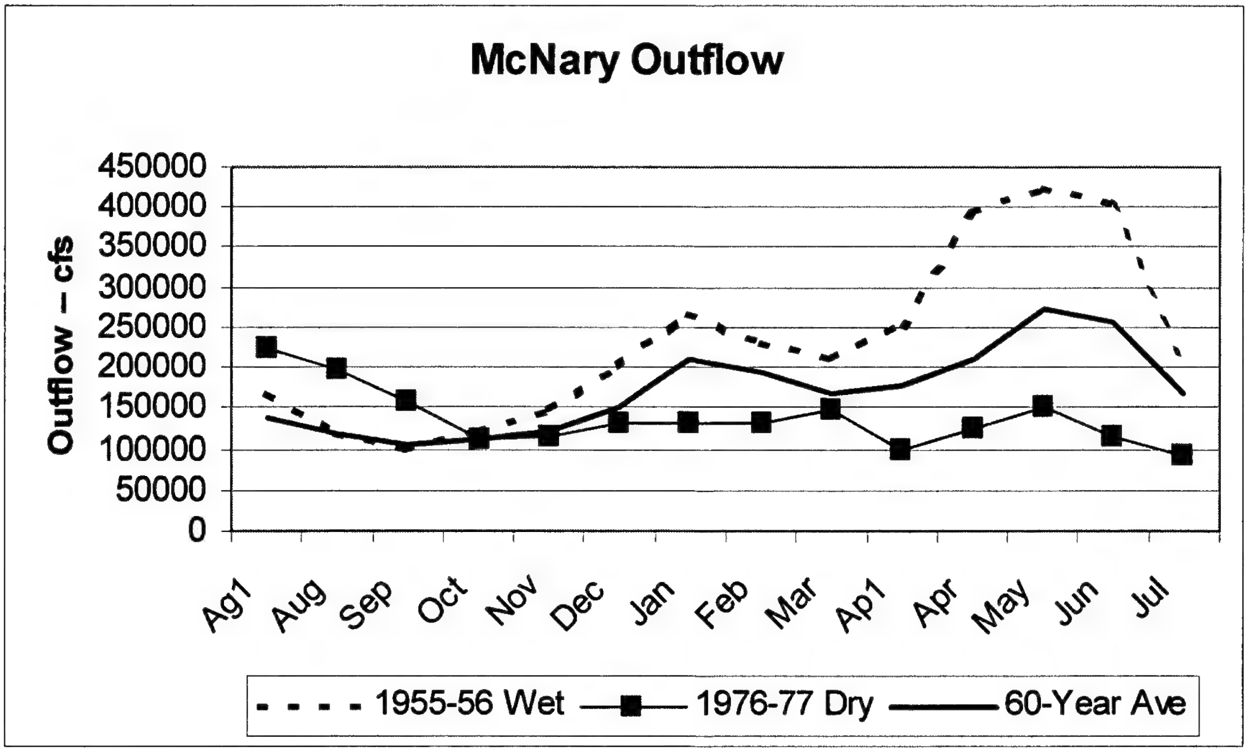


Figure B-8 Alternative B2 Graphs (continued)



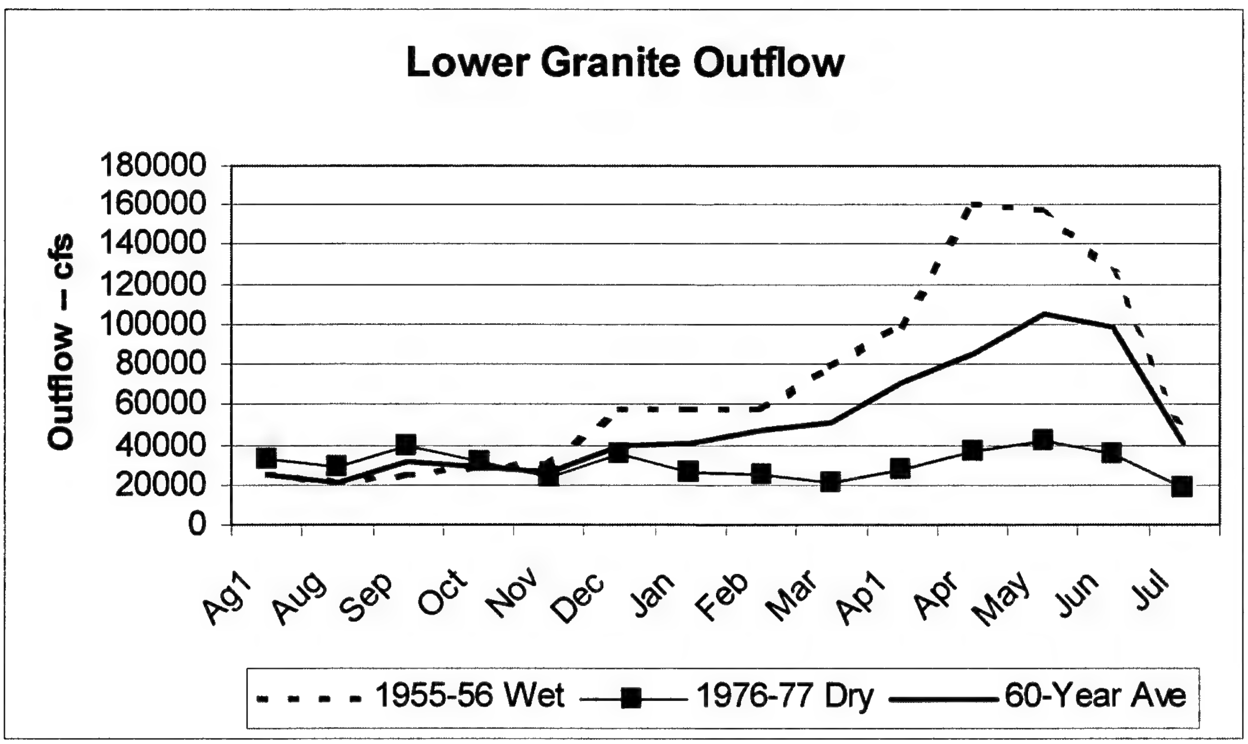
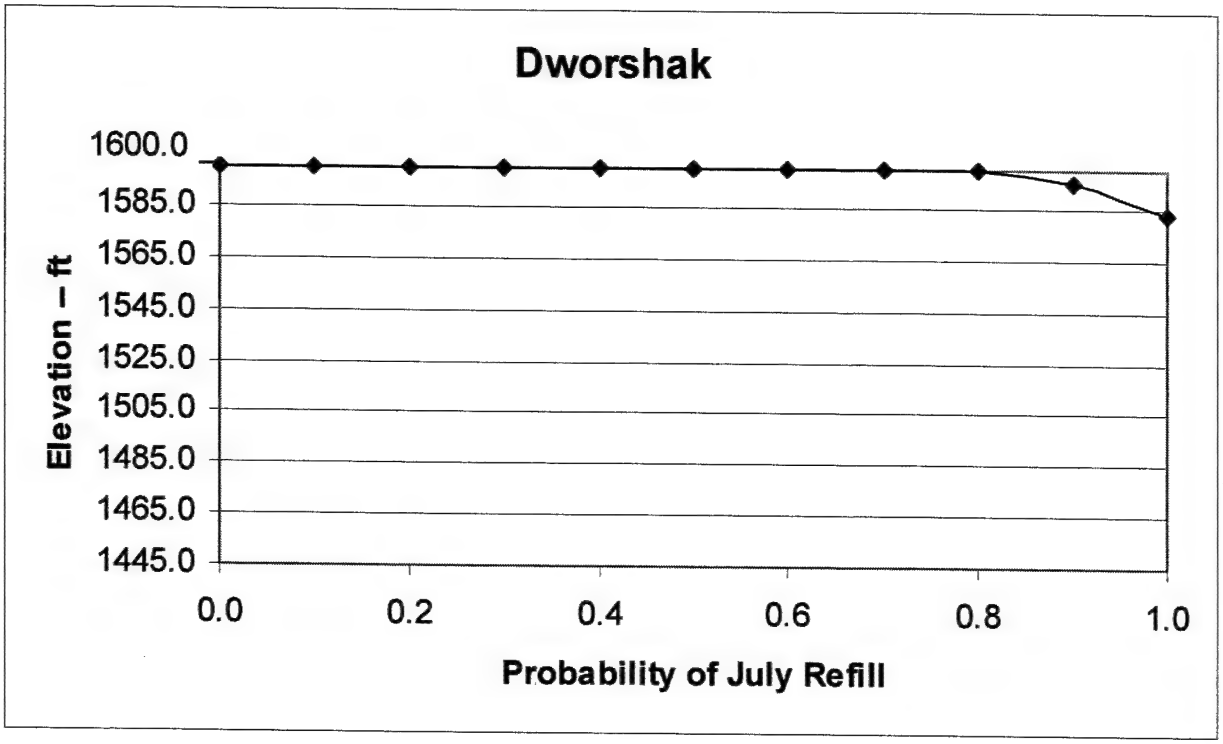


Figure B-8 Alternative B2 Graphs (continued)



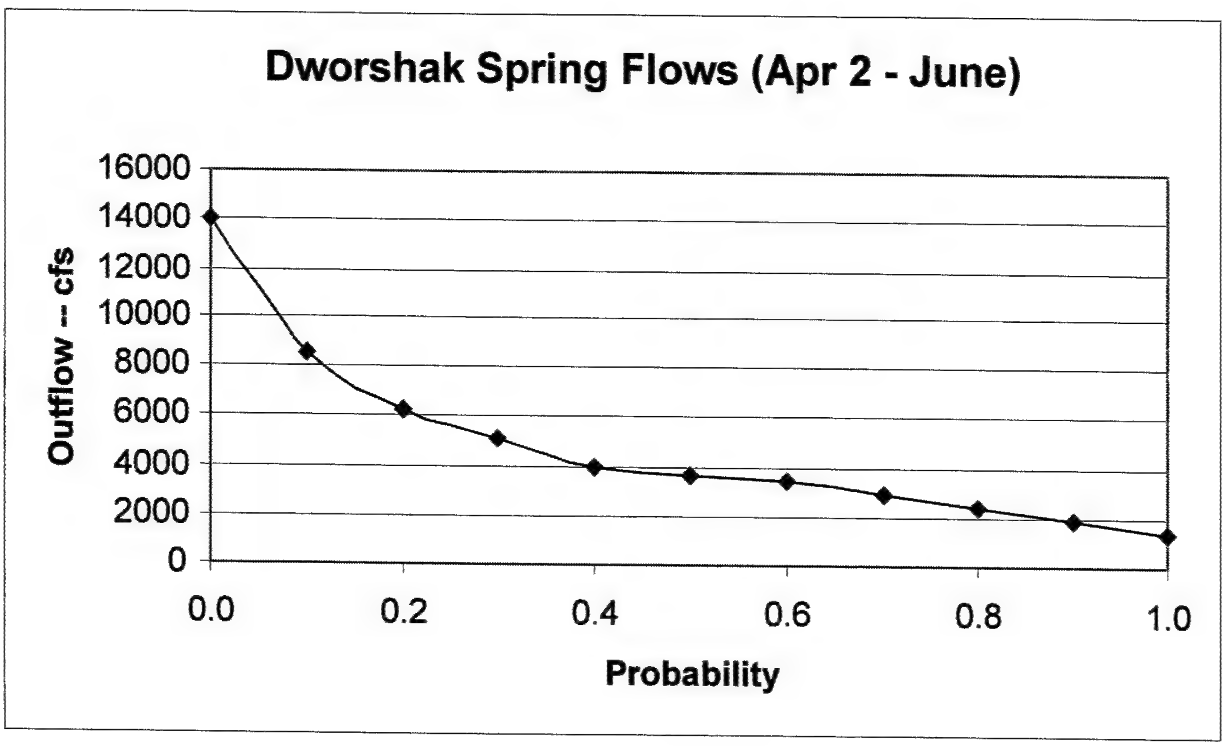
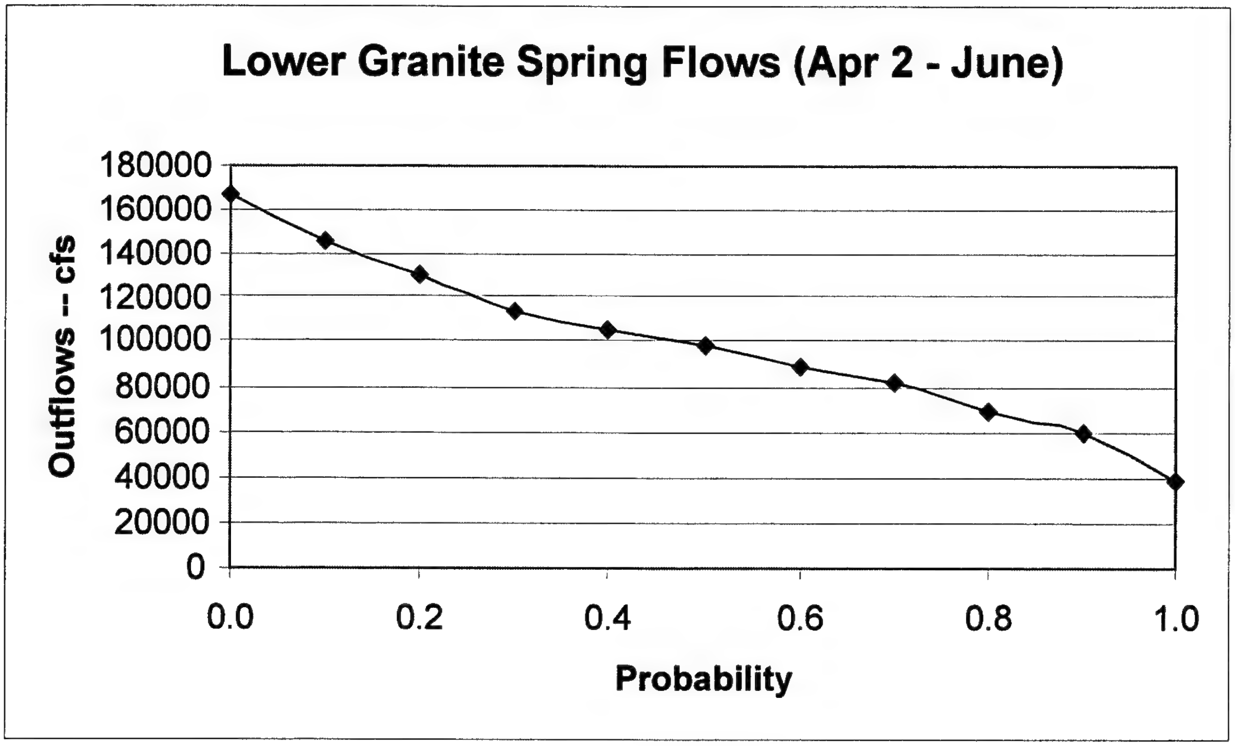


Figure B-8 Alternative B2 Graphs (continued)



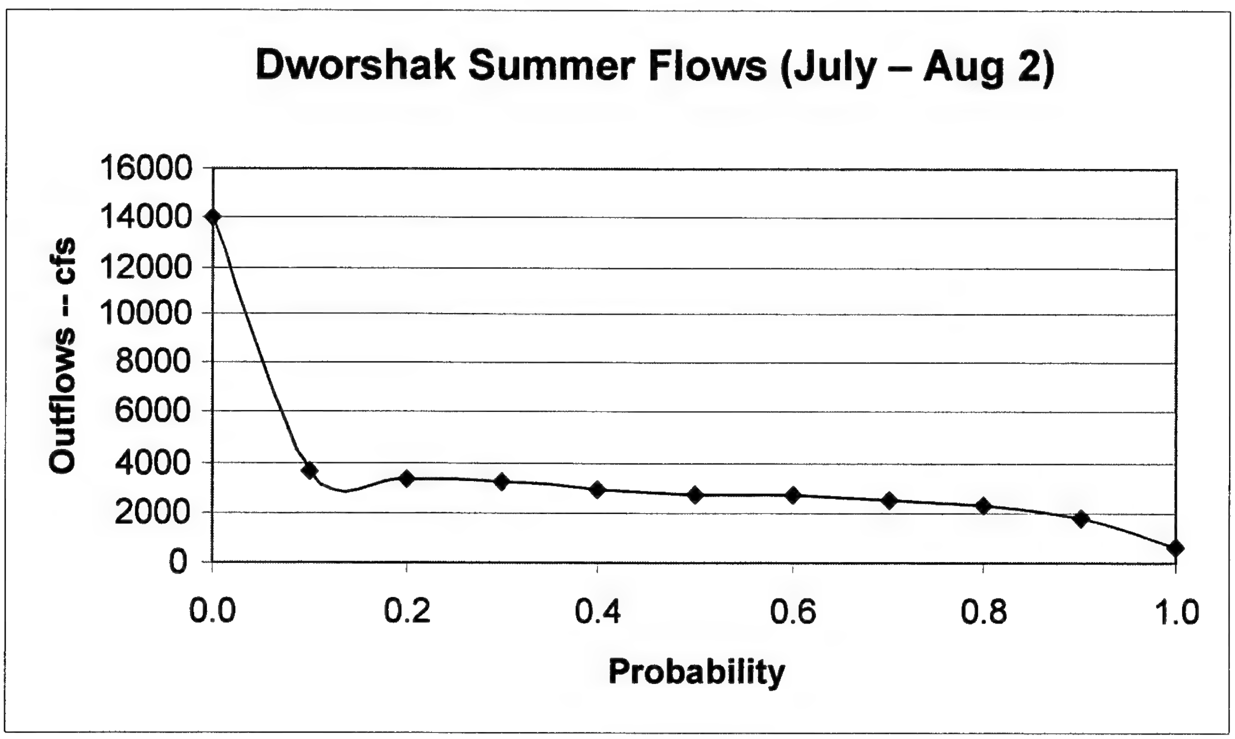


Figure B-8 Alternative B2 Graphs (continued)

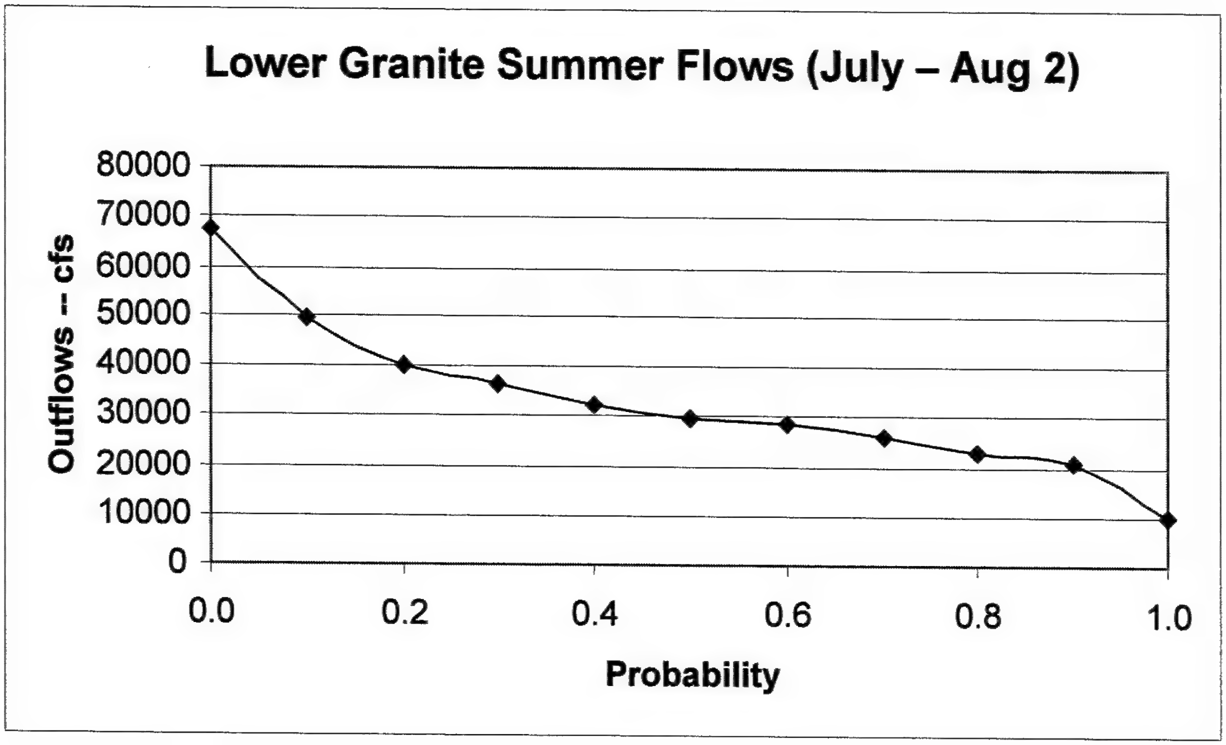
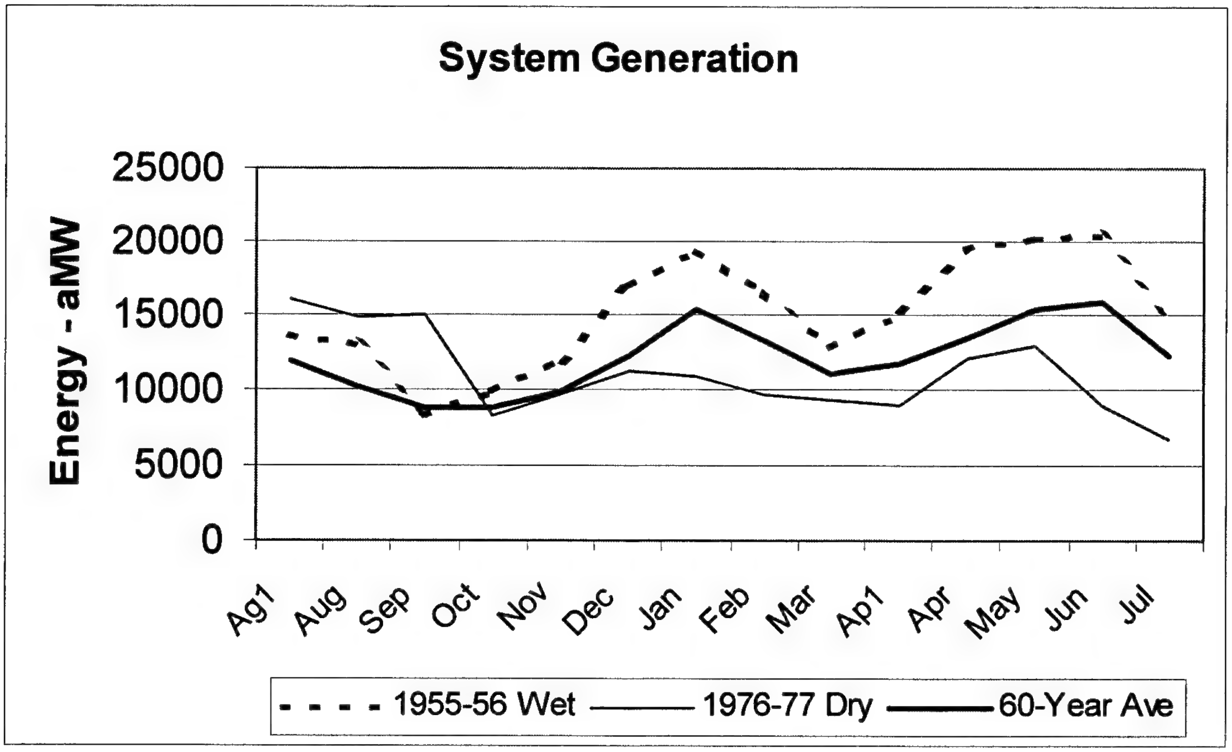


Figure B-9 Alternative C1 Graphs



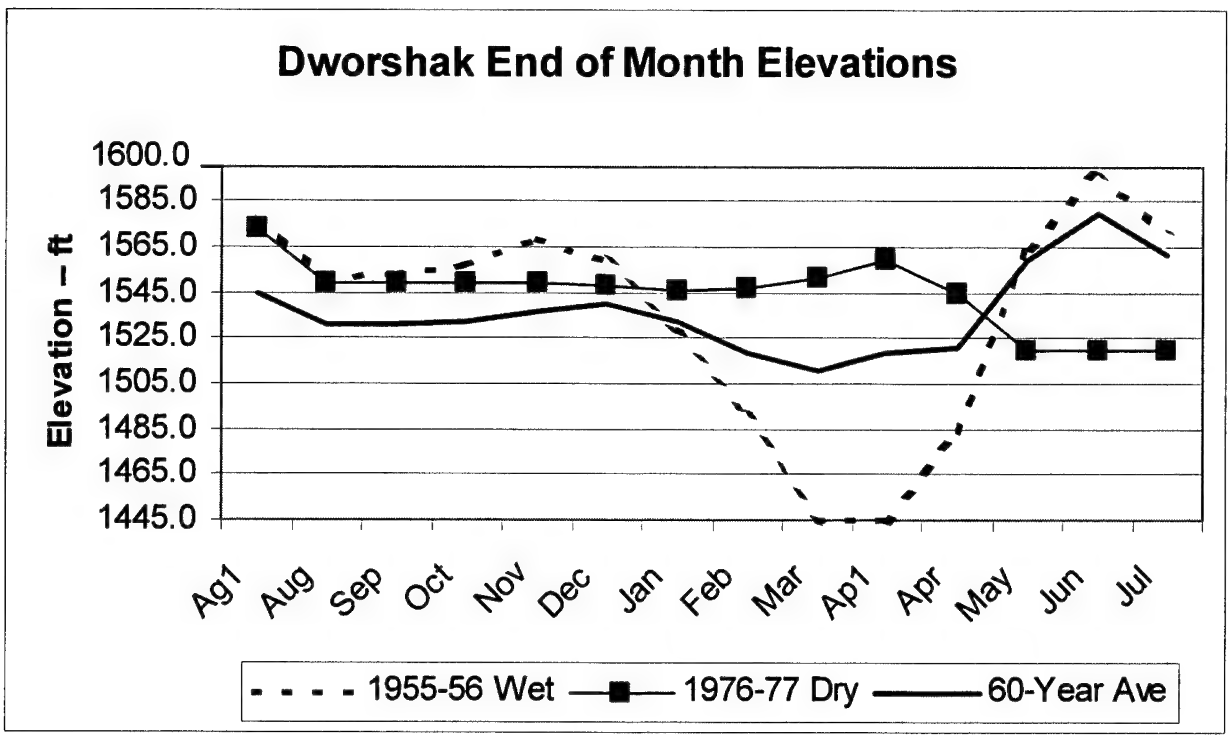
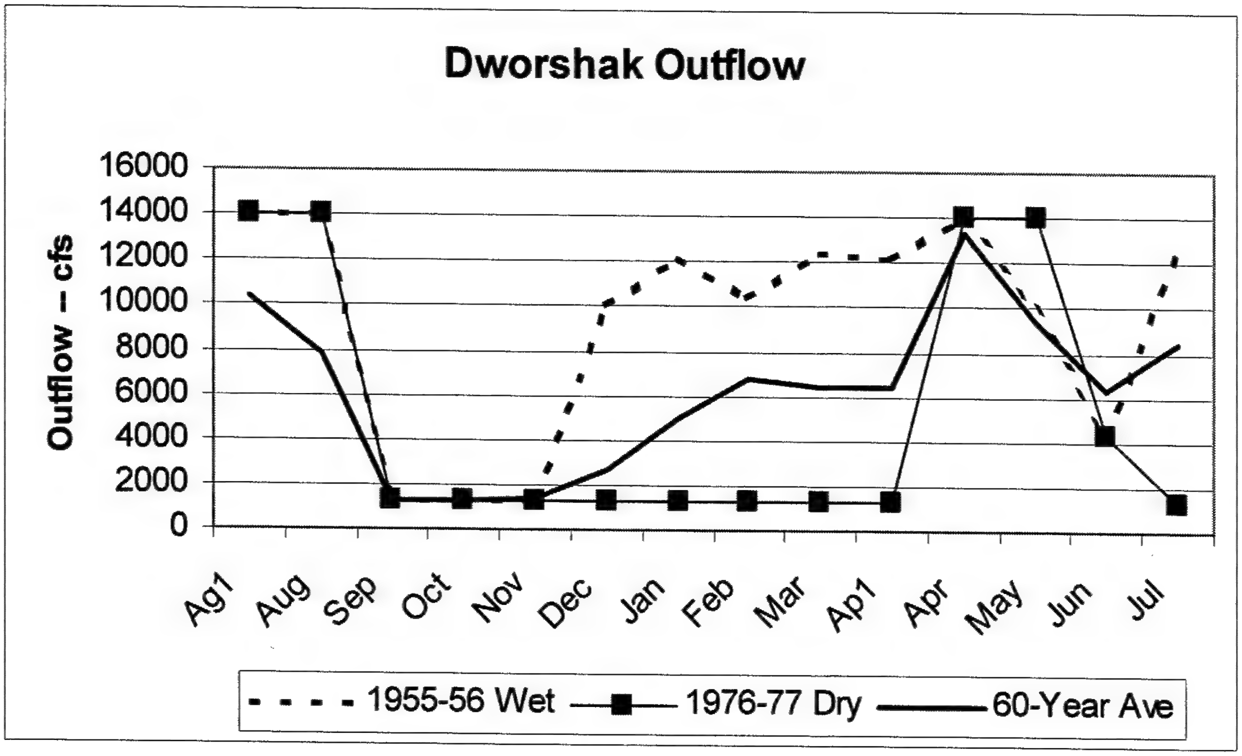


Figure B-9 Alternative C1 Graphs (continued)



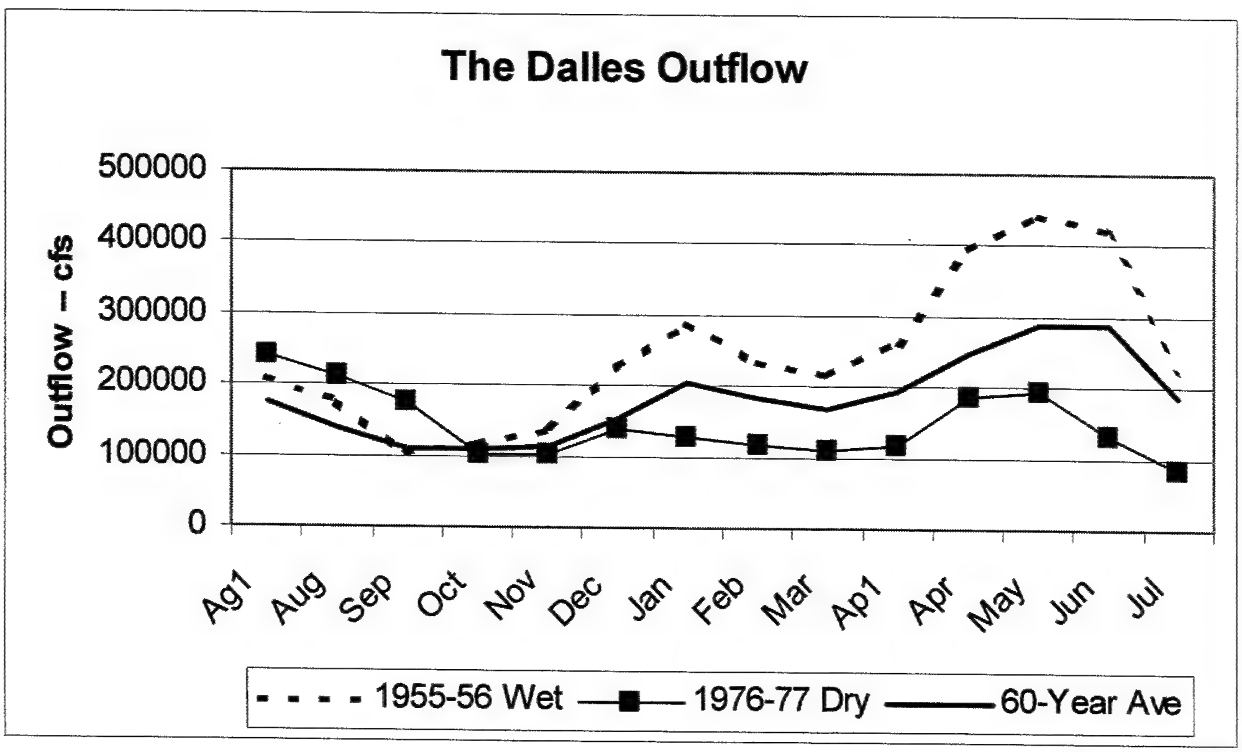
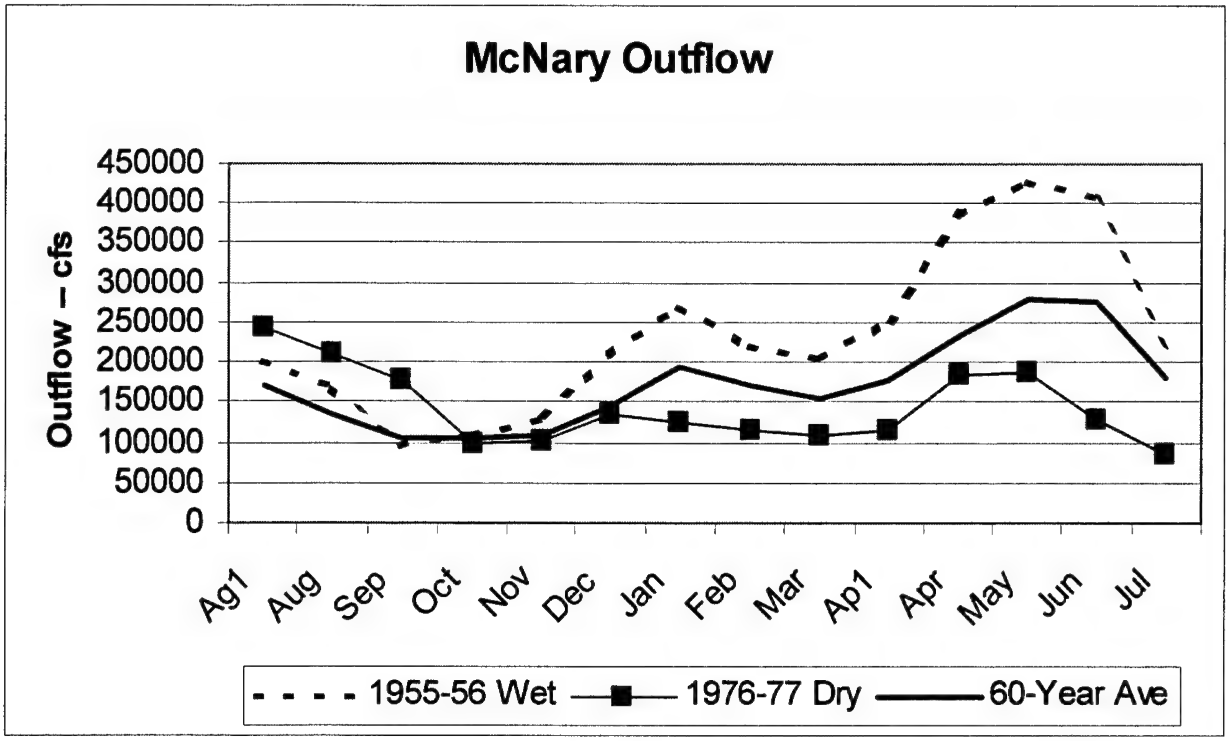


Figure B-9 Alternative C1 Graphs (continued)



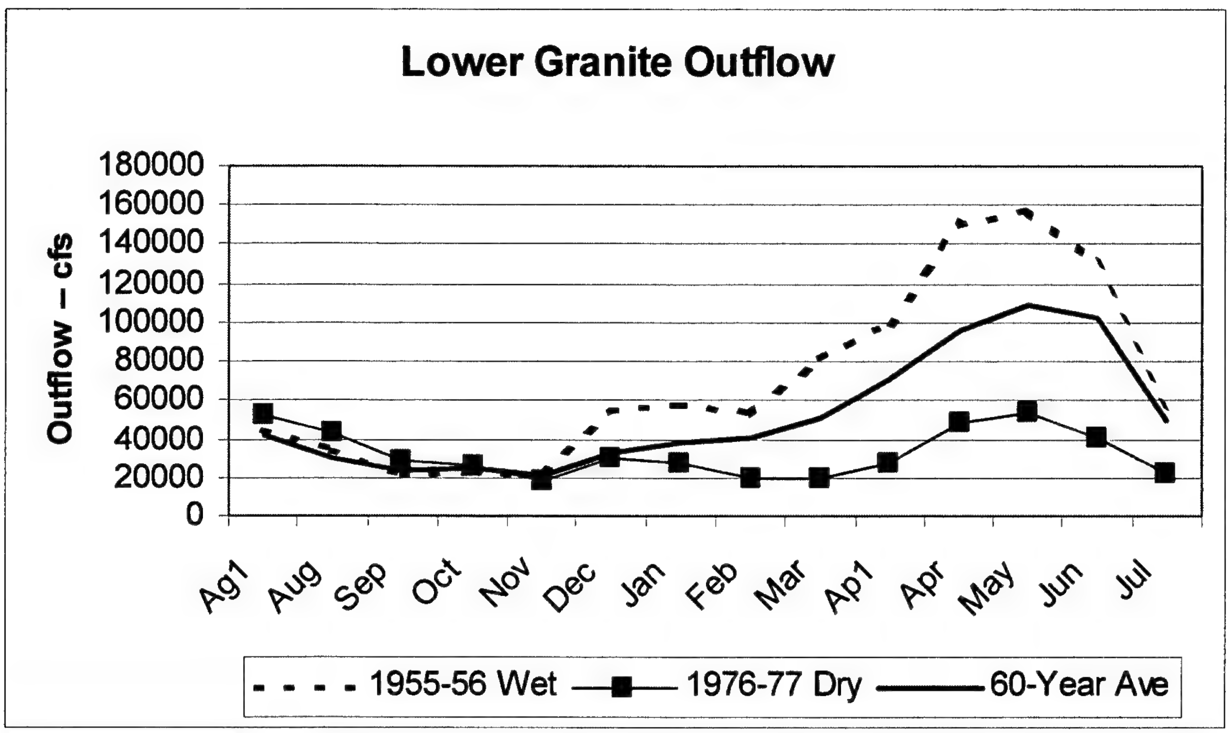
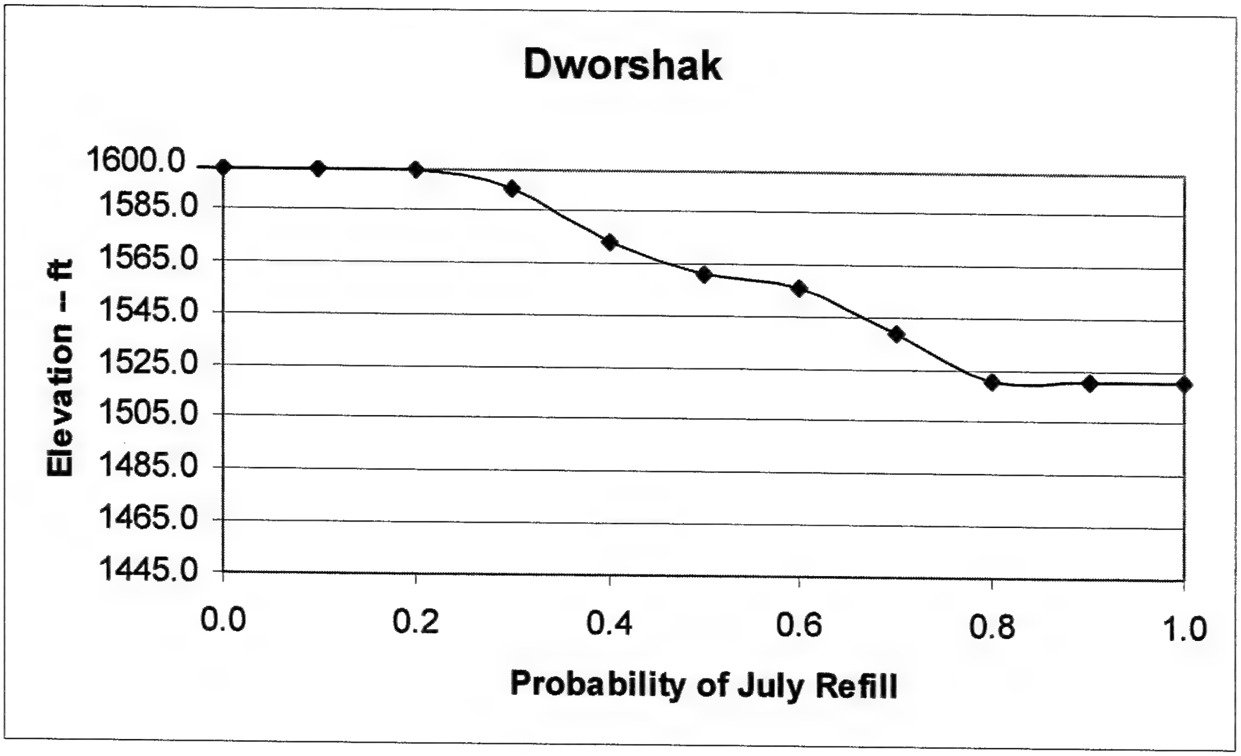


Figure B-9 Alternative C1 Graphs (continued)



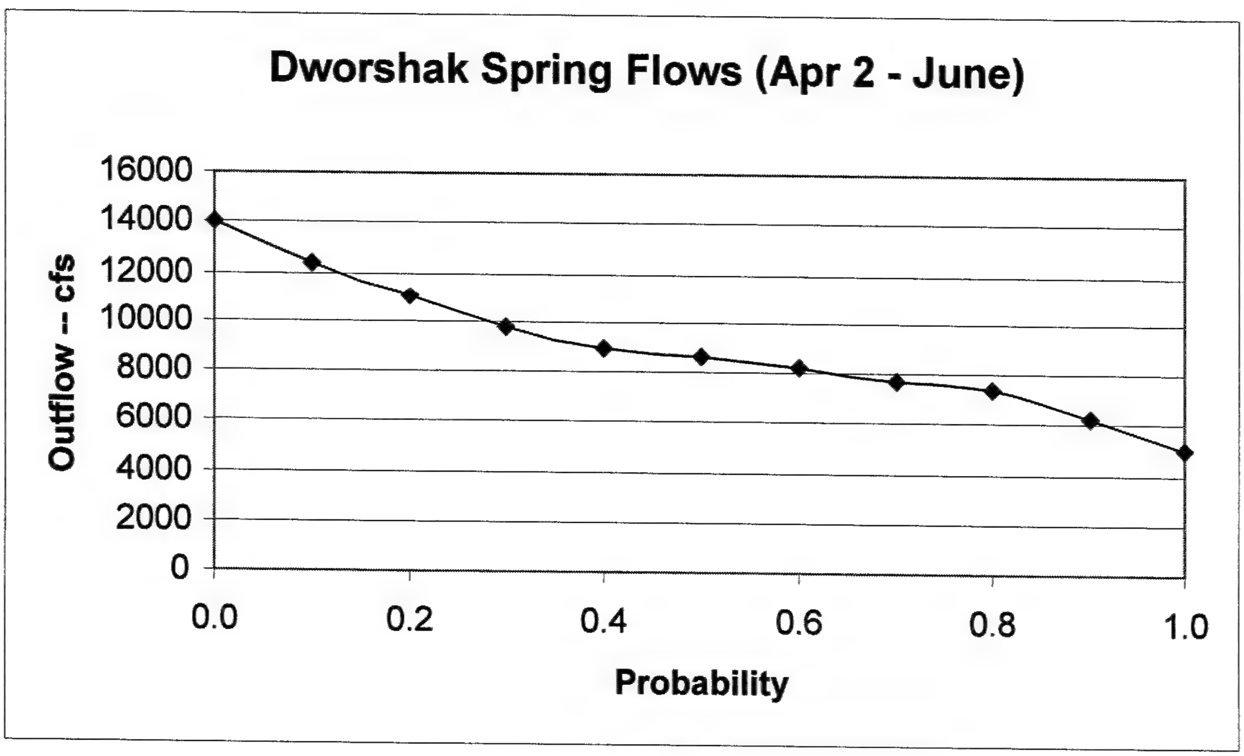
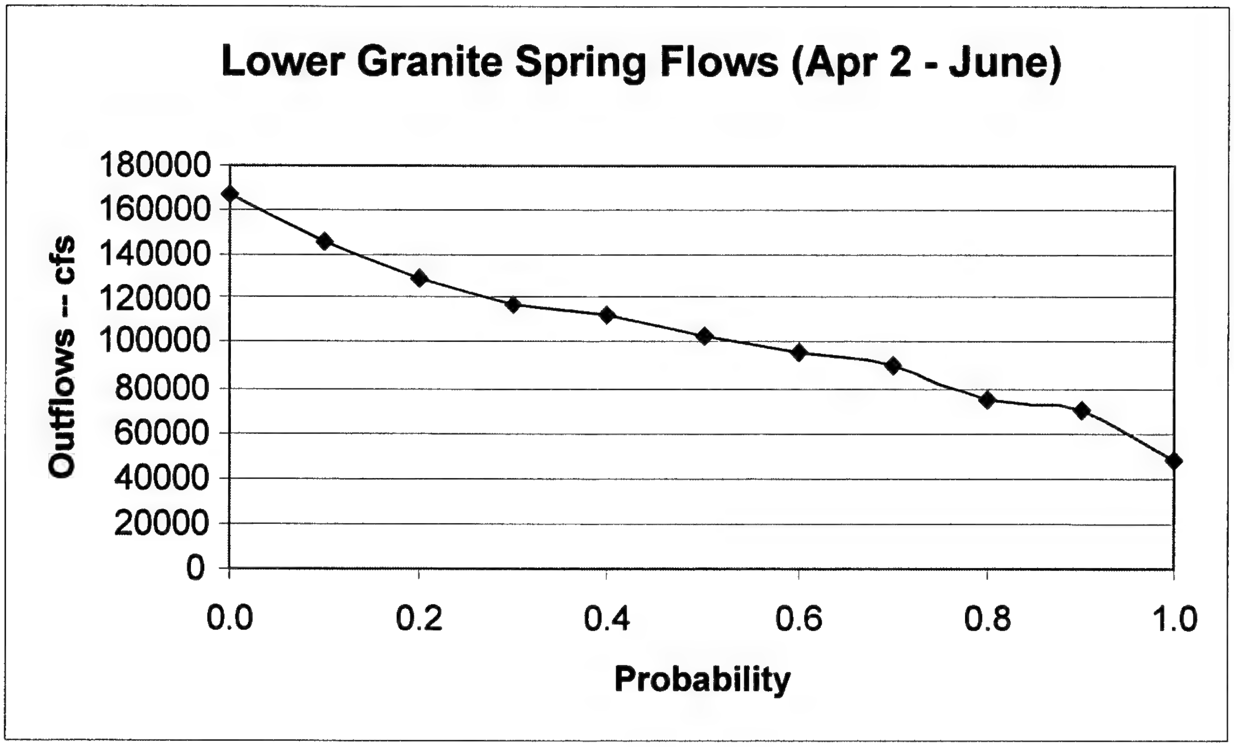


Figure B-9 Alternative C1 Graphs (continued)



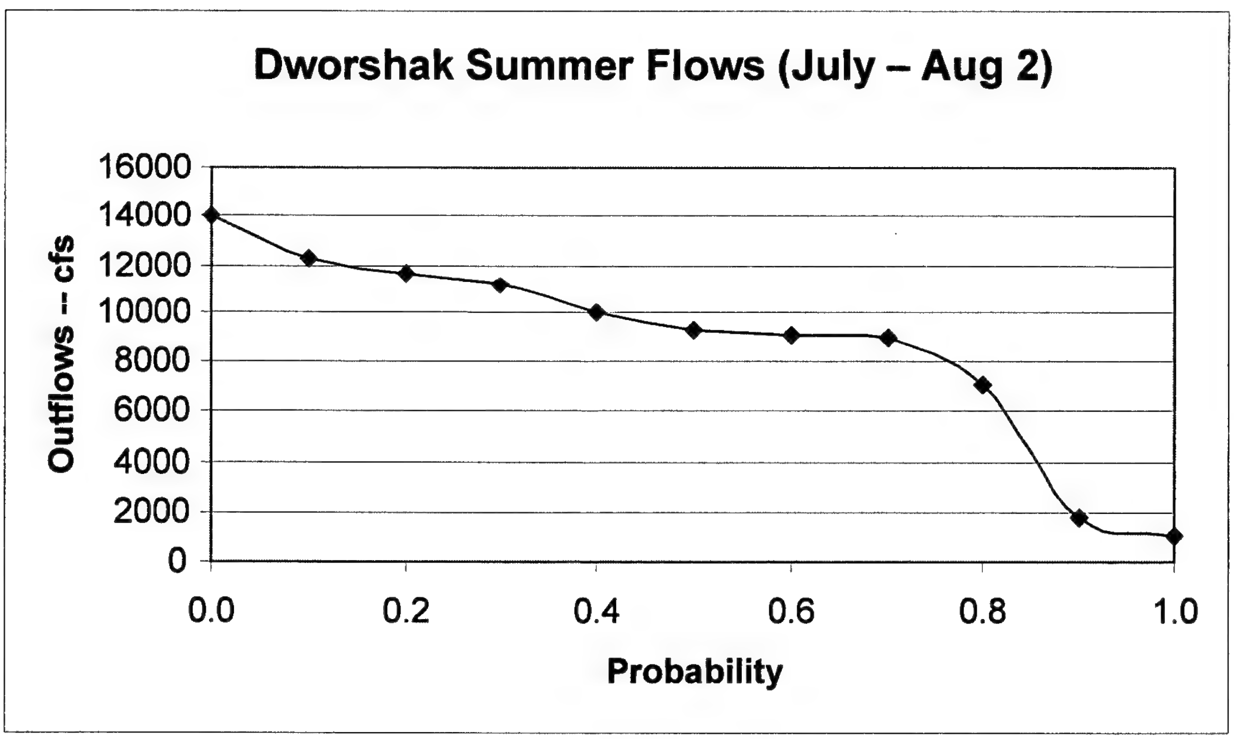


Figure B-9 Alternative C1 Graphs (continued)

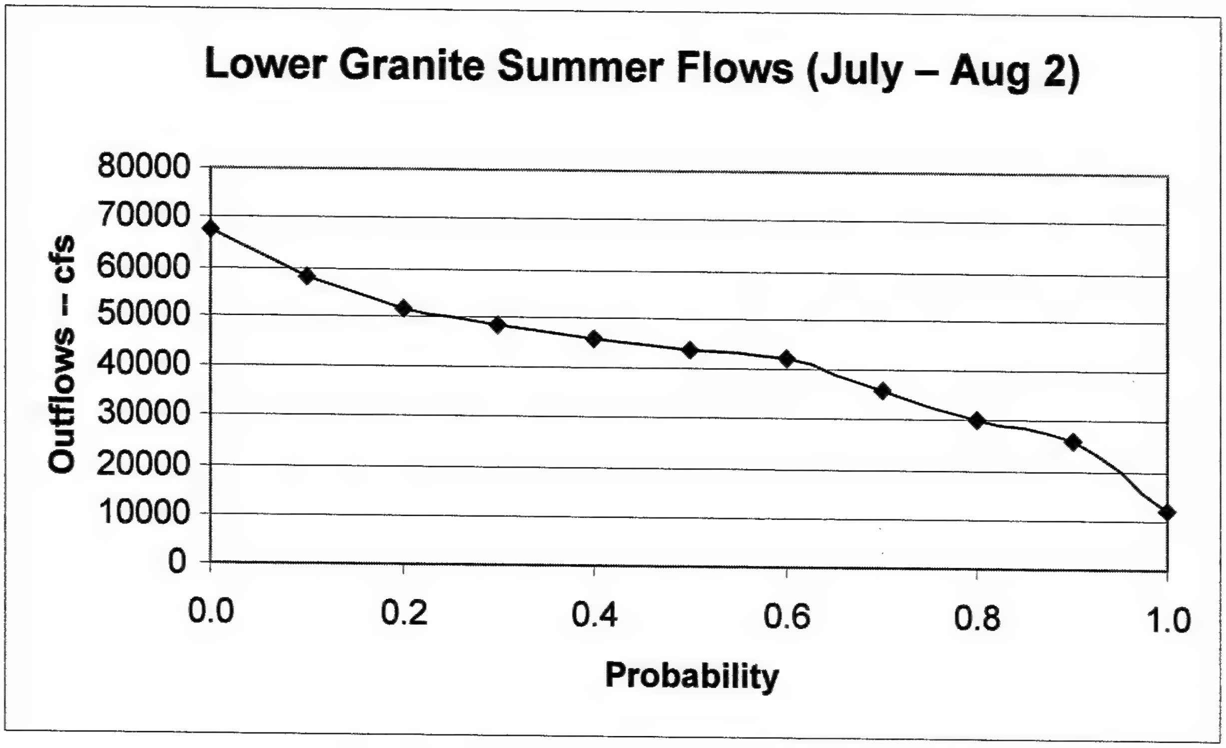
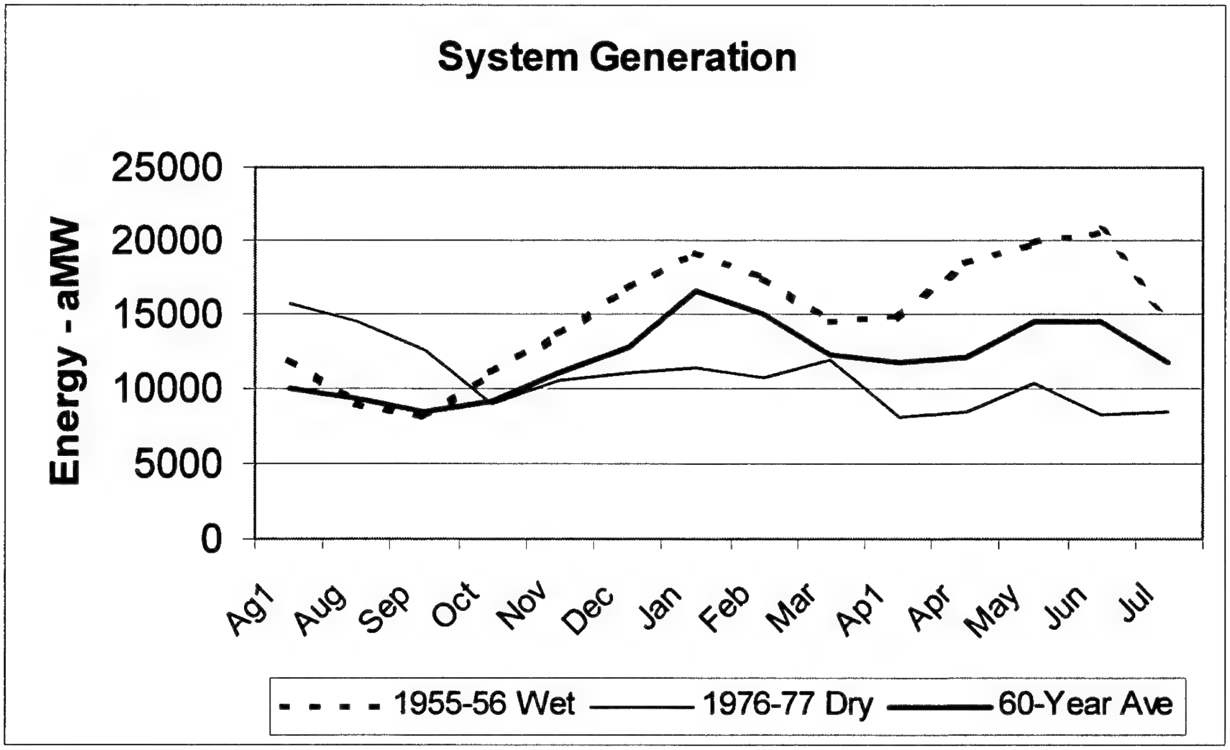


Figure B-10 Alternative C2 Graphs



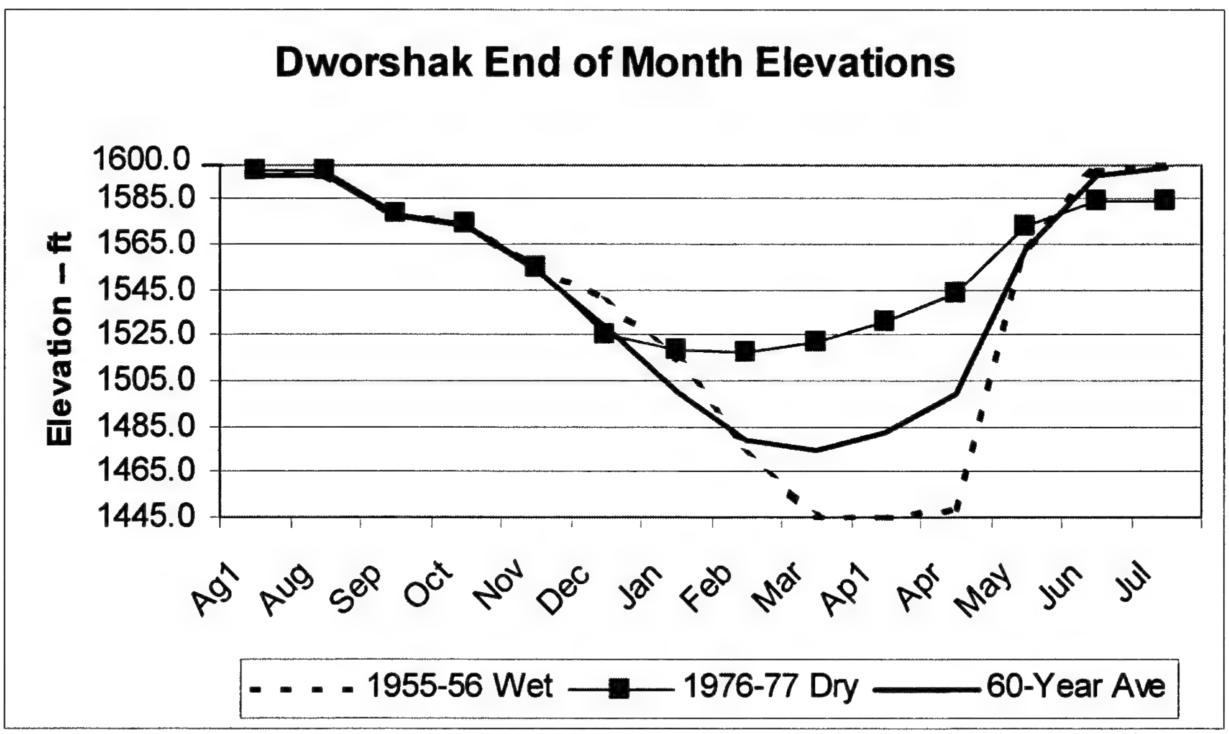
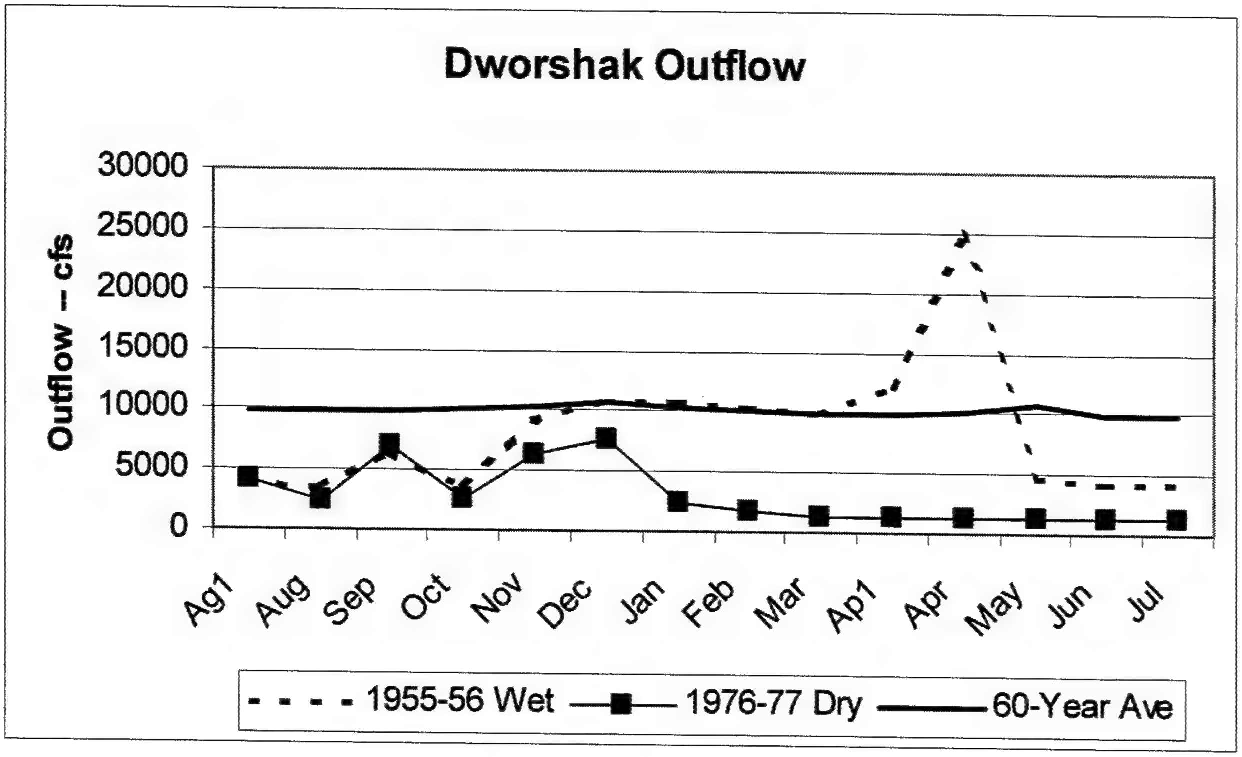


Figure B-10 Alternative C2 Graphs (continued)



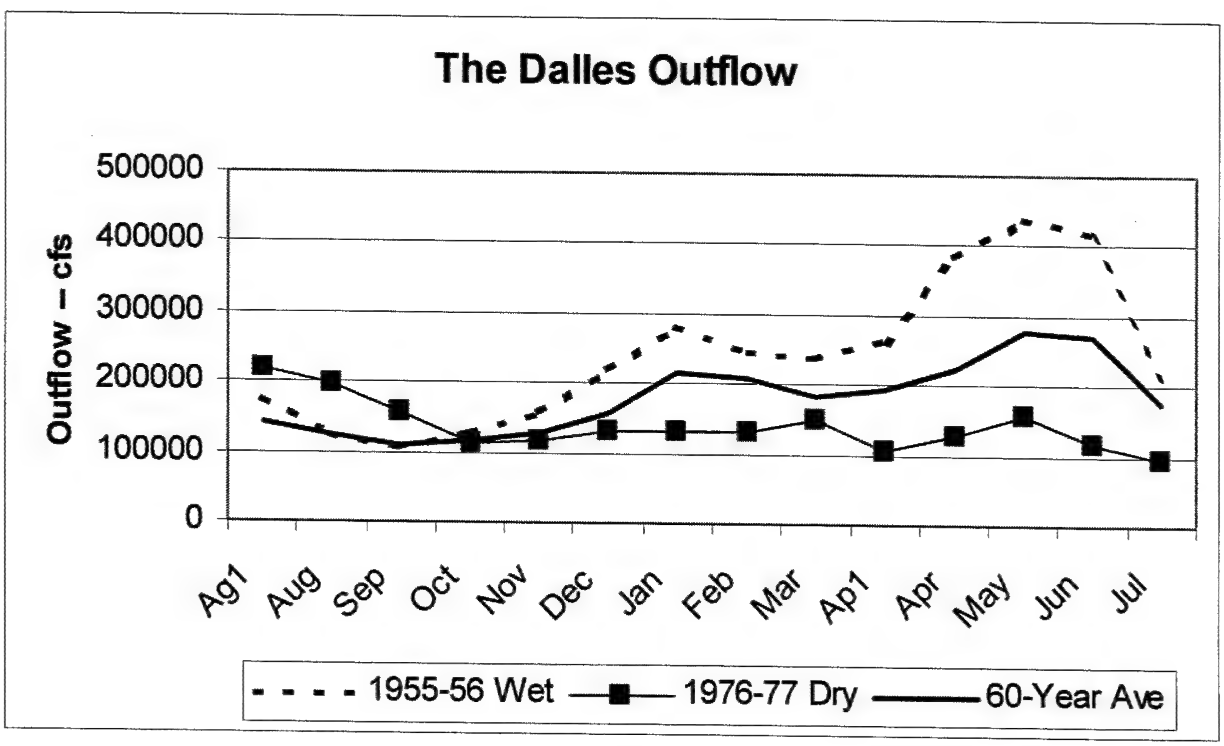
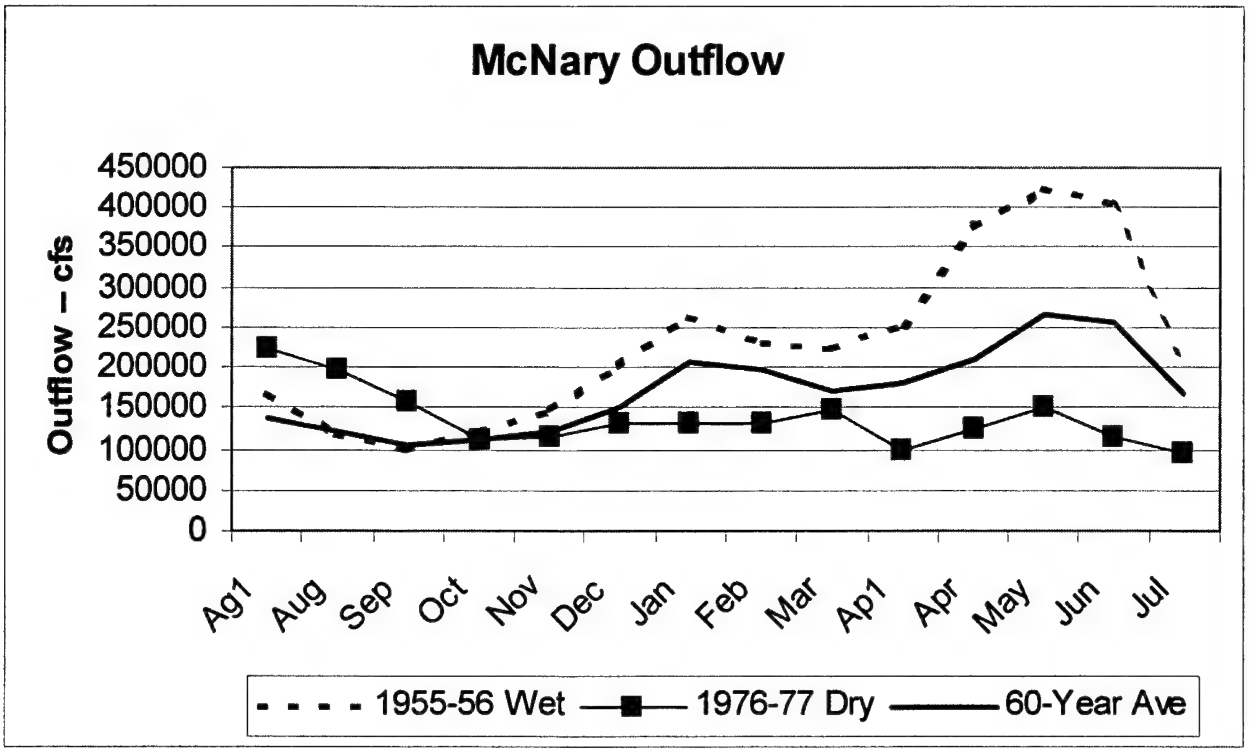


Figure B-10 Alternative C2 Graphs (continued)



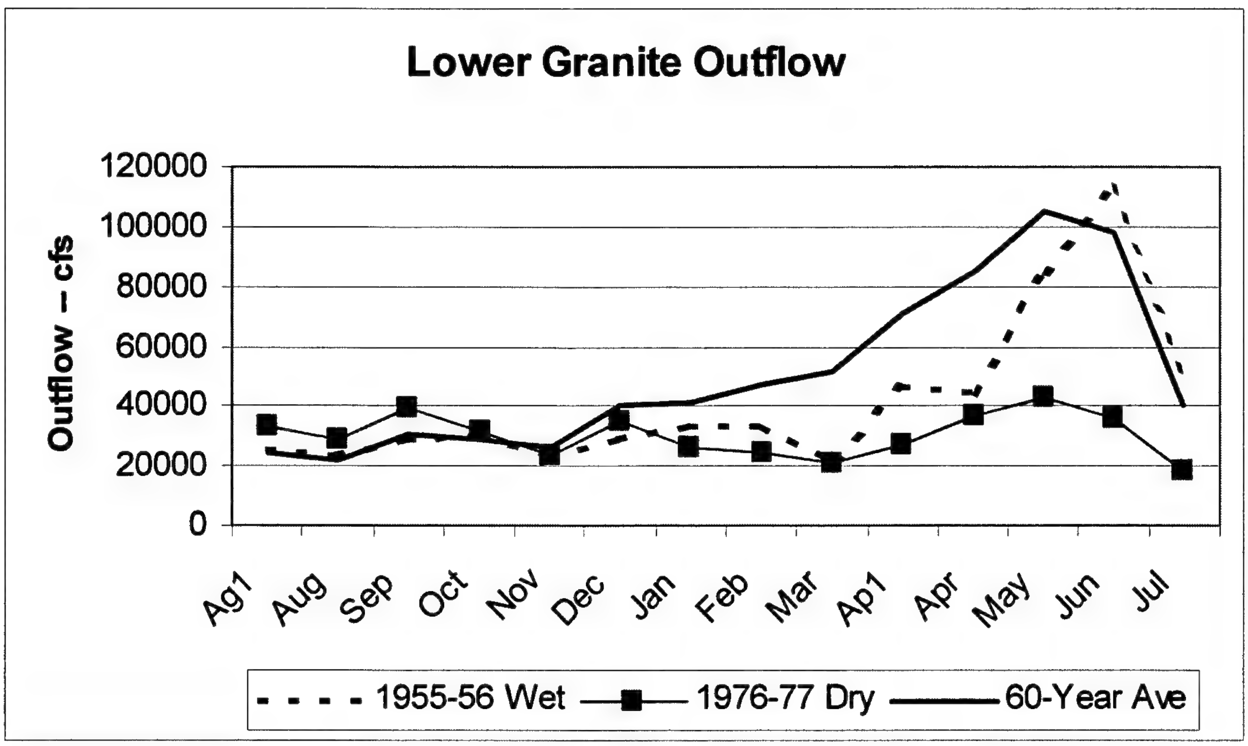
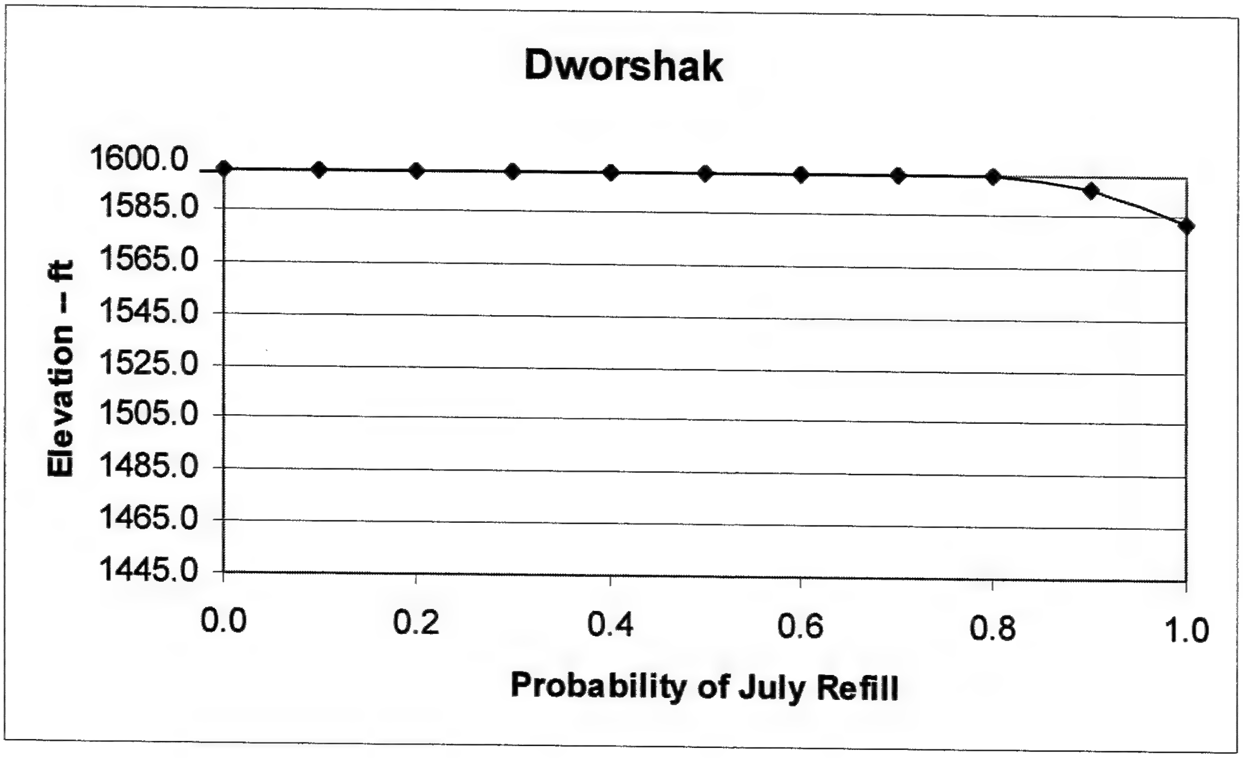


Figure B-10 Alternative C2 Graphs (continued)



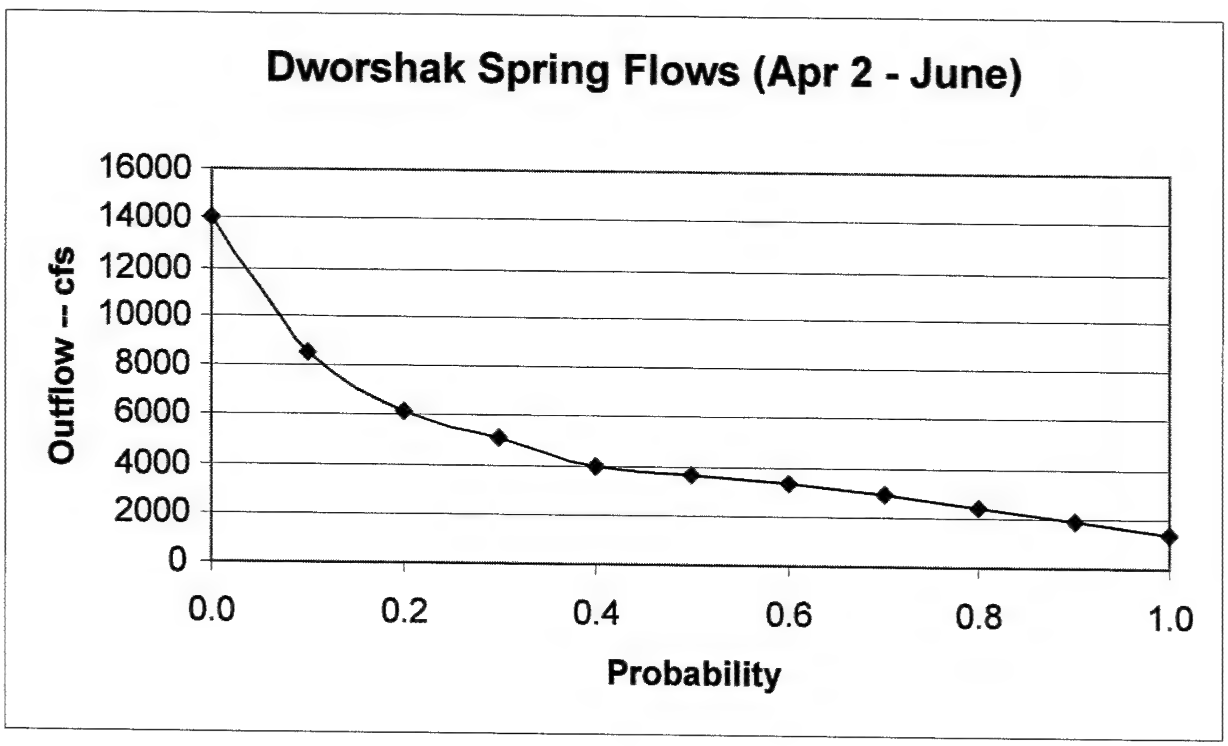
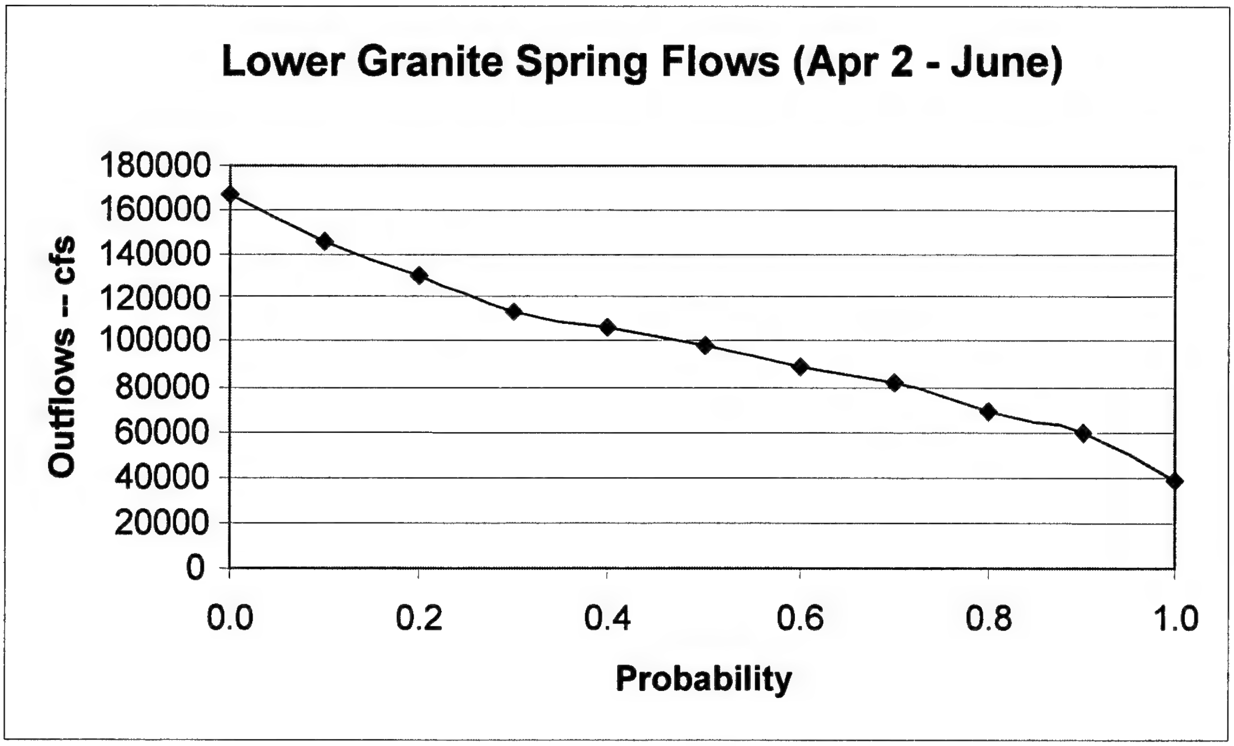


Figure B-10 Alternative C2 Graphs (continued)



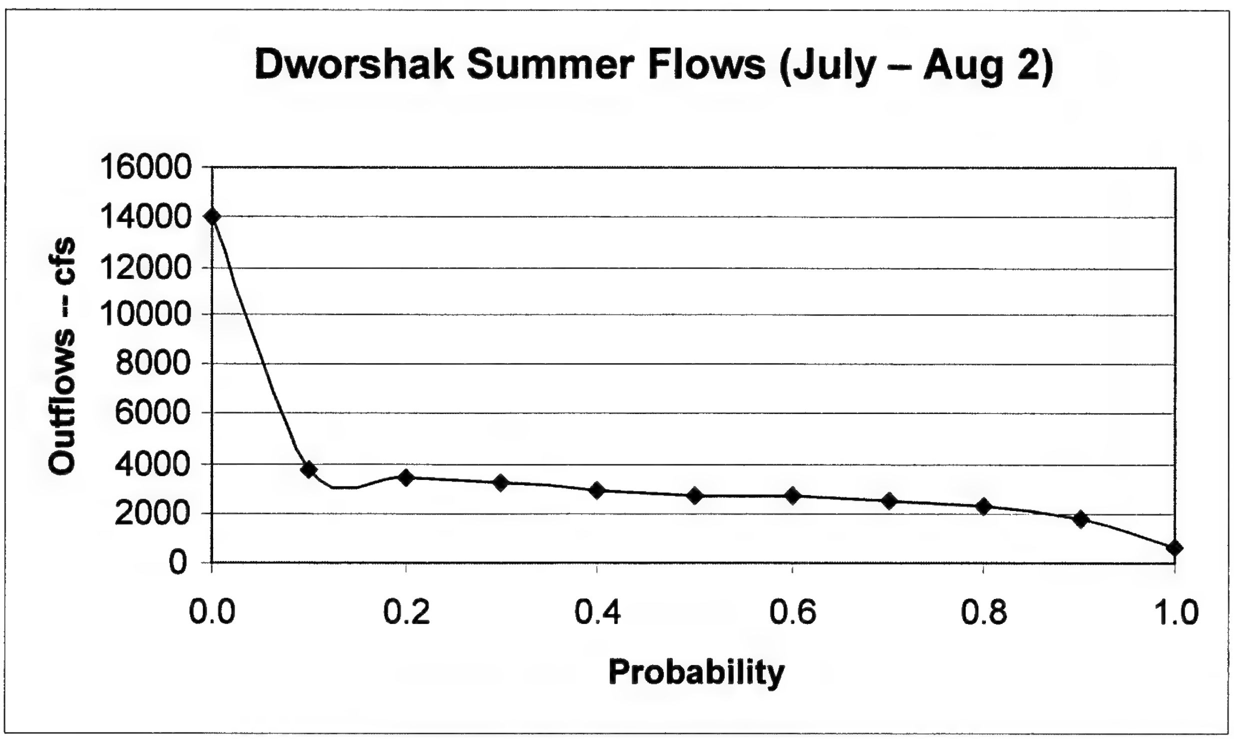
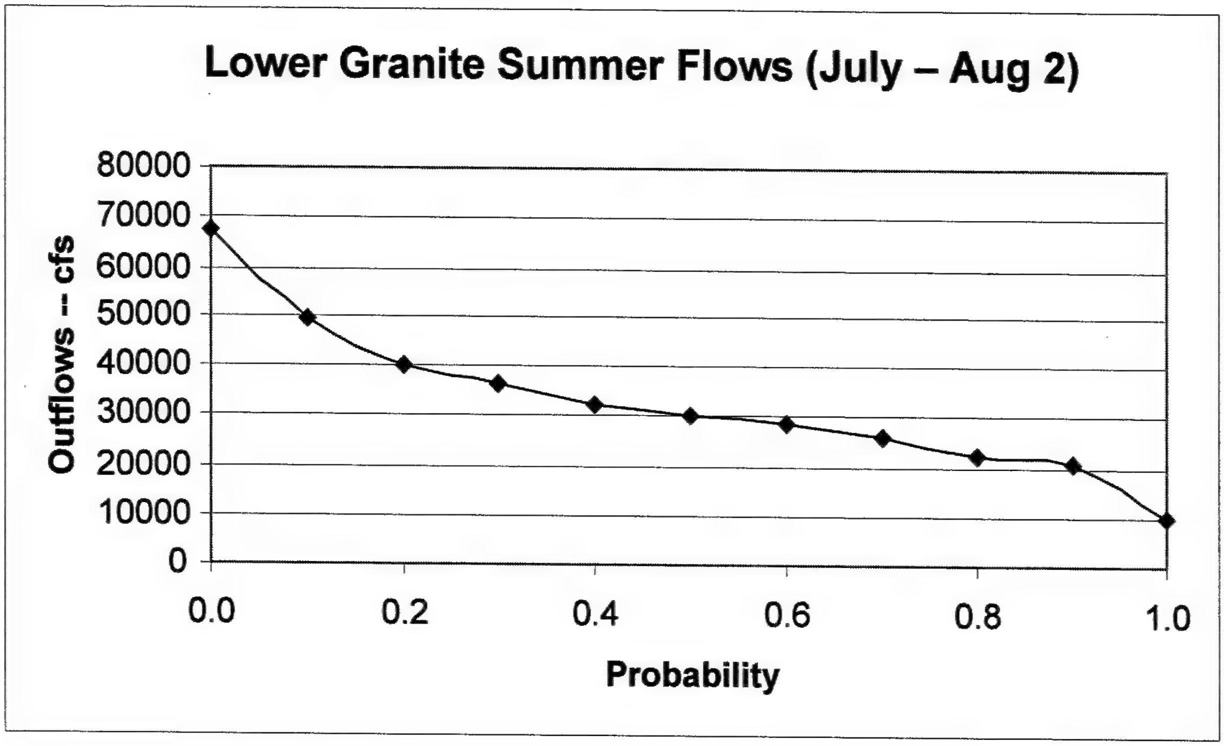


Figure B-10 Alternative C2 Graphs (continued)



This page intentionally left blank

US Army Corps
of Engineers®
Walla Walla District

Final

Lower Snake River Juvenile Salmon Migration Feasibility Report/ Environmental Impact Statement

---

Appendix H
Fluvial Geomorphology

February 2002

US Army Corps
of Engineers®
Walla Walla District

Final
Lower Snake River Juvenile Salmon Migration Feasibility Report/ Environmental Impact Statement

---

Appendix H
Fluvial Geomorphology

Produced by

Pacific Northwest National Laboratory

Produced for

U.S. Army Corps of Engineers
Walla Walla District

February 2002

H:\WP\1346\Appendices\FEIS\H - Fluvial Geo\CamRdy\App_H.doc

FOREWORD

Appendix H was prepared by Pacific Northwest National Laboratory in conjunction with the U.S. Army Corps of Engineers' (Corps) study team. This appendix is one part of the overall effort of the Corps to prepare the Lower Snake River Juvenile Salmon Migration Feasibility Report/Environmental Impact Statement (FR/EIS).

The Corps has reached out to regional stakeholders (Federal agencies, tribes, states, local governmental entities, organizations, and individuals) during the development of the FR/EIS and appendices. This effort resulted in many of these regional stakeholders providing input and comments, and even drafting work products or portions of these documents. This regional input provided the Corps with an insight and perspective not found in previous processes. A great deal of this information was subsequently included in the FR/EIS and appendices; therefore, not all of the opinions and/or findings herein may reflect the official policy or position of the Corps.

This page is intentionally left blank.

CONTENTS

CONTENTS

FIGURES

FIGURES

TABLES

ACRONYMS AND ABBREVIATIONS

2D	two-dimensional
AEI	Agricultural Enterprises, Inc.
AGU	American Geophysical Union
ANCOOR	Analytical Coordination Workgroup
ASCE	American Society of Civil Engineers
BA	Biological Assessment
BOR	Bureau of Reclamation
BPA	Bonneville Power Administration
CCC	Civilian Conservation Corps
CEQ	Council on Environmental Quality
cfs	cubic feet per second
Corps	U.S. Army Corps of Engineers
DEM	digital elevation model
DGAS	Dissolved Gas Abatement Study
DREW	Drawdown Regional Economic Workgroup
EIS	environmental impact statement
ESA	Endangered Species Act
FCRPS	Federal Columbia River Power System
Feasibility Study	Lower Snake River Juvenile Salmon Migration Feasibility Study
FR	Federal Register
FR/EIS	Lower Snake River Juvenile Salmon Migration Feasibility Report/ Environmental Impact Statement
GIS	Geographic Information System
IDFG	Idaho Department of Fish and Game
IDFG v. NMFS	*Idaho Department of Fish and Game v. National Marine Fisheries Service*
ISG	Independent Scientific Group
M&I	municipal and industrial
MASS1	Modular Aquatic Simulation System 1D
MASS2	Modular Aquatic Simulation System 2D
MOA	Memorandum of Agreement
MOP	minimum operating pool
NED	national economic development
NEPA	National Environmental Policy Act
NGVD	National Geodetic Vertical Datum
NMFS	National Marine Fisheries Service
NPPC	Northwest Power Planning Council
OA/EIS	Columbia River Salmon Flow Measures Options Analysis/Environmental Impact Statement
P	river sinuosity
PATH	Plan for Analyzing and Testing Hypotheses
PNCA	Pacific Northwest Coordination Agreement
PNW RRF	Pacific Northwest River Reach Files

ACRONYMS AND ABBREVIATIONS

RKM	River Kilometer
RM	River Mile
ROD	Record of Decision
SCS	System Configuration Study
SEIS	Supplemental Environmental Impact Statement
SOR	System Operation Review
SOS	System Operating Strategies
SRSRT	Snake River Salmon Recovery Team
TAG	Technical Advisory Group
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
WPPSS	Washington Public Power Supply System
WSCC	Western Systems Coordinating Council

ENGLISH TO METRIC CONVERSION FACTORS

To Convert From	To	Multiply By
LENGTH CONVERSIONS:		
Inches	Millimeters	25.4
Feet	Meters	0.3048
Miles	Kilometers	1.6093
AREA CONVERSIONS:		
Acres	Hectares	0.4047
Acres	Square meters	4047
Square Miles	Square kilometers	2.590
VOLUME CONVERSIONS:		
Gallons	Cubic meters	0.003785
Cubic yards	Cubic meters	0.7646
Acre-feet	Hectare-meters	0.1234
Acre-feet	Cubic meters	1234
OTHER CONVERSIONS:		
Feet/mile	Meters/kilometer	0.1894
Tons	Kilograms	907.2
Tons/square mile	Kilograms/square kilometer	350.2703
Cubic feet/second	Cubic meters/sec	0.02832
Degrees Fahrenheit	Degrees Celsius	(Deg F –32) x (5/9)

Executive Summary

Background

Four dams on the lower Snake River have created a nearly continuous reservoir system, reducing the availability of riverine habitat and impacting life history strategies for all populations of Snake River salmonids. Snake River populations of salmon and steelhead have declined during the past 30+ years. As a result, National Marine Fisheries Services (NMFS) listed several species of salmon and steelhead as threatened or endangered under the Endangered Species Act (ESA). In 1995, NMFS issued a Biological Opinion calling for an evaluation of structural and operational modifications to the four hydroelectric dams operated by the U.S. Army Corps of Engineers (Corps) on the lower Snake River. The Lower Snake River Juvenile Salmon Migration Feasibility Study—Interim Status Report was released in 1995 as a result of this action. Of the drawdown scenarios considered in the Interim Status Report (e.g., seasonal, yearlong, variable discharges, variable elevation), only permanent drawdown is currently being evaluated. This alternative entails the breaching of the earthen portion of each of the four lower Snake River dams (Ice Harbor, Lower Monumental, Little Goose, and Lower Granite). The Independent Scientific Group of the Northwest Power Planning Council (NPPC) and NMFS have suggested that breaching the four lower Snake River dams could be beneficial not only to migrating juvenile salmonids, but also to those salmonids that spawn and rear in the mainstem Snake River (e.g., fall chinook salmon and steelhead trout).

Objectives

The investigation of channel morphology (Part 1 of this Appendix H) set out to address the question, "To what extent can mainstem habitats and riverine processes required for salmon production be achieved by near-dam breaching?" The first objective was to describe the physical characteristics and habitats of the pre-dam river. The second objective was to quantify the geomorphic features that describe salmon production areas. The third objective was to evaluate changes in the flow regime under near-dam breaching.

The objectives of the hydrodynamic modeling (Part 2 of this Appendix H) were to compare hydraulic conditions and sediment mobility in the lower Snake River for current and natural river conditions using mathematical models of the river system.

Approach

The study area extended from the mouth of the Snake River near Pasco, Washington, at the confluence with the Columbia River, to River Kilometer (RKM) 266 (River Mile (RM) 165) near the confluence with the Grande Ronde River. In general, the methods for all studies integrated pre-dam river data and hydraulic modeling into a geographic information system (GIS). The water discharge data used for all modeling and analysis was derived from U.S. Geological Survey (USGS) gage data and adjusted streamflow and storage data from the Bonneville Power Administration (BPA, 1993).

Pre-dam channel characteristics were evaluated by classifying the lower Snake River into distinct geomorphic units at two different scales: watershed and reach. The watershed-scale classification was based on geology and physiography, as well as channel planform data from pre-dam maps (ca.

1934). Reach scale classification and characterization (e.g., stream power, pool/riffle/run) was based on the analysis of hydraulic geometry and channel morphology at sampled cross sections. Hydraulics at each cross section were simulated using one-dimensional (MASS1) and two-dimensional (MASS2) unsteady flow models.

Potential fall chinook spawning and rearing habitat was identified and then quantified by two separate methods: 1) a geomorphic spawning habitat model for fall chinook was developed by integrating historic, pre-dam spawning data (e.g., location, redd density) with geomorphic characteristics, and 2) spawning and rearing habitat criteria was applied to the hydrodynamic conditions simulated by flow models.

Estimates of flows required to mobilize sediments after drawdown were also estimated by two methods: 1) using simulated depth-averaged velocities from MASS2, in combination with sediment movement criteria based on critical velocity or shear stress, and, 2) using the geomorphic competency method which uses a threshold of 1.0-year flood based on the annual maximum series.

Conclusions

Our analysis indicated that, prior to impoundment, the lower Snake River exhibited heterogeneous characteristics ranging from those typical of alluvial reaches to those typical of bedrock-confined reaches in large rivers. In general, the pre-dam channel was a morphologically diverse, coarse-bedded, stable river, possessing a meandering thalweg and classic pool-riffle longitudinal bedform profile.

The geomorphic model of fall chinook spawning habitat and the application of habitat criteria to MASS2 estimates differed somewhat in the location and amount of spawning habitat that would be available with the natural river alternative. The geomorphic model identified 54.9 percent of the lower Snake River reach as potential spawning habitat while the application of habitat criteria predicted 23.5 percent.

Analysis of historic and contemporary discharge records indicates that regulated flow regimes under dam breaching will be competent enough to maintain channel characteristics and riverine processes (e.g., channelbed mobilization). The time required before the realization of these characteristics and processes depends on many interrelated factors, including an initial 5-year to 10-year period of erosion and transport of fine sediments accumulated in the reservoirs since dam construction. After the bulk of those fine sediments are removed, the competency of the regulated flow regime (particularly the annual maximum discharge) will be sufficient to mobilize the channelbed surface.

Flows required for mobilization of coarse sediment under the dam breaching alternative were estimated at 95,600 cfs using the geomorphic competency method and a threshold of 1.0-year flood and at 111,500 cfs using the MASS2 predicted velocities and shear stress criteria multiplied by 1.5 to allow for added energy required to initiate motion in a resting particle.

The time required for the initiation of such processes depends on the annual flow regimes during the period following drawdown, particularly the frequency and duration of annual maximum discharge equaling or exceeding the pre-major storage period.

Part 1

Assessment of Restoring Pre-dam Channel Morphology, Salmonid Habitats, and Riverine Processes through Drawdown: Snake River

1. Introduction

1.1 Objectives

The research described herein set out to address the question, "To what extent can mainstem habitats and riverine processes required for salmon production be achieved by near-dam breaching?" We focused on three objectives for this study. The first objective was to describe the physical characteristics and habitats of the pre-dam river. Characterizing and quantifying the pre-dam channel morphology provides a starting point for determining future channel characteristics and habitats because it establishes the difference between known pre-dam channel morphology and present day conditions. The second objective was to quantify the geomorphic features that describe salmon production areas. The third objective was to evaluate changes in the flow regime under near-dam breaching—perhaps the most important controlling factor of channel morphology and riverine processes. This objective is particularly important because the river will continue to be influenced by regulated flows from the operation of upstream storage reservoirs and hydropower facilities located on the mainstem Snake River and tributaries (e.g., the Hells Canyon Dam complex in the middle Snake River and Dworshak Dam on the North Fork of the Clearwater River). The regulated flow regimes must be competent enough to erode and transport fine sediments accumulated in the reservoirs since dam construction, and also to maintain other geomorphic processes (e.g., channelbed mobilization).

1.2 Background

Snake River populations of salmon and steelhead have declined during the past 30+ years, leading to their protection under the U. S. Endangered Species Act (ESA). In 1991, Snake River sockeye salmon (*Oncorhynchus nerka*) were listed under the ESA as endangered. In 1992, Snake River spring/summer and fall chinook salmon (*O. tshawytscha*) were listed as threatened. In 1998, Snake River steelhead (*O. mykiss*) were listed as threatened. These listings prompted the National Marine Fisheries Service (NMFS) to call for an evaluation of structural and operational modifications to the four hydroelectric dams operated by the U. S. Army Corps of Engineers (Corps) on the lower Snake River (NMFS, 1995; NMFS, 1998).

There is a nearly continuous reservoir system on the lower Snake River since the construction of the four lower Snake River dams (1961 to 1975). The only areas currently exhibiting riverine characteristics are the tailraces downriver of each dam. The lack of riverine habitat has impacted the life history strategies (e.g., juvenile migration from tributary to ocean) for all populations of Snake River salmonids.

Early modifications to dam operations were focused on reducing travel time through the reservoirs for the juveniles during their spring migration. One method used for increasing water velocity, and thereby reducing travel times, was to increase the spill volume through the dams (also known as drawdown).

Recent work indicates that alluvial reaches of large rivers are particularly important to the spawning success of fall chinook salmon (Geist and Dauble, 1998; Dauble and Geist, In Press). Alluvial rivers are those that are capable of shaping their own bed and bank—they are self-formed (Richards, 1982). Their channel morphology results from the entrainment, transportation, and deposition of

unconsolidated sediments throughout the channel course (Richards, 1982). This morphology is maintained in "dynamic quasi-equilibrium"—where sediment is transported through or stored within the channel (dynamic), but the channel morphology remains relatively stable over time (quasi-equilibrium) even though the channel may not be static (Richards, 1982; Knighton, 1984). In ideal alluvial rivers, this morphological relationship is maintained when the rates of sediment supply and sediment transport are roughly equal (Hey, 1997). Natural alluvial channels are morphologically diverse. They exhibit a classic pool-riffle longitudinal profile where deeper pool sections alternate with the shallower inflection areas of riffles (Hey, 1997). Historical accounts of salmonid spawning in the lower Snake River (Fulton, 1968; Fulton, 1970) suggest that some segments exhibited alluvial characteristics prior to dam construction.

The rehabilitation and enhancement of pre-dam biotic and abiotic components in the lower Snake River depends on the extent to which pre-dam morphological characteristics can be restored—particularly alluvial and partially-alluvial reaches. This approach assumes that those characteristics supported healthy salmonid populations in the past and have the capacity to do so in the future.

2. Study Area

The area studied for this appendix extends from the mouth of the Snake River (at its confluence with the Columbia River) to 165 miles upriver near the confluence with the Grande Ronde River (Figure 2-1). The lower Snake River watershed drains approximately 104,000 square miles (mi^2) of Idaho and Washington. Mean annual discharge at the uppermost dam in the area studied (Lower Granite Dam) is 49,800 cubic feet per second (cfs), while mean annual peak discharge is approximately 169,257 cfs computed from a 1959 to 1998 period of record. This value is slightly larger than the 163,000 cfs 2-year value shown on frequency curve 2 (page F9-3) of Appendix F, Hydrology/Hydraulics and Sedimentation. This difference is due to different periods of record being used for the computations. The study area lies within a climatic area that receives average annual precipitation of 16 inches, with average maximum winter temperatures of 40° Fahrenheit (F) and average August temperatures of 64° F. The dominant potential vegetation types are warm-dry shrublands, warm-dry herbaceous lands, and cool-moist shrublands (Quigley and Arbelbide, 1997).

Elevations in the study area range from 340 to 3000 feet above mean sea level, and include areas of broad valleys with gentle slopes, as well as areas of deep, confined canyons with steep walls. The lower Snake River valley has a complex geologic history. Basalt bedrock, originating during periods of volcanism between 17 and 6 million years ago represents much of the current river valley (Schuster et al., 1997), forming steep, bedrock-exposed valley walls known as the Snake River breaks. About 14,500 years ago, Pleistocene Lake Bonneville (in present-day northern Utah) spilled over and flooded into the Snake River valley, depositing significant amounts of alluvium with clast diameter ranging in size from less than 10 centimeters to more than 10 meters (O'Connor, 1993). The flood followed the course of the present-day Snake and Columbia rivers before entering the Pacific Ocean (O'Connor 1993). Subsequent flood events (as many as 100) from glacial Lake Missoula, between 14,500 and 12,000 years ago, deposited immense amounts of gravel, sand, and silt over the Bonneville flood deposits in the lower end of the study area (Baker and Bunker, 1985; O'Connor, 1993).

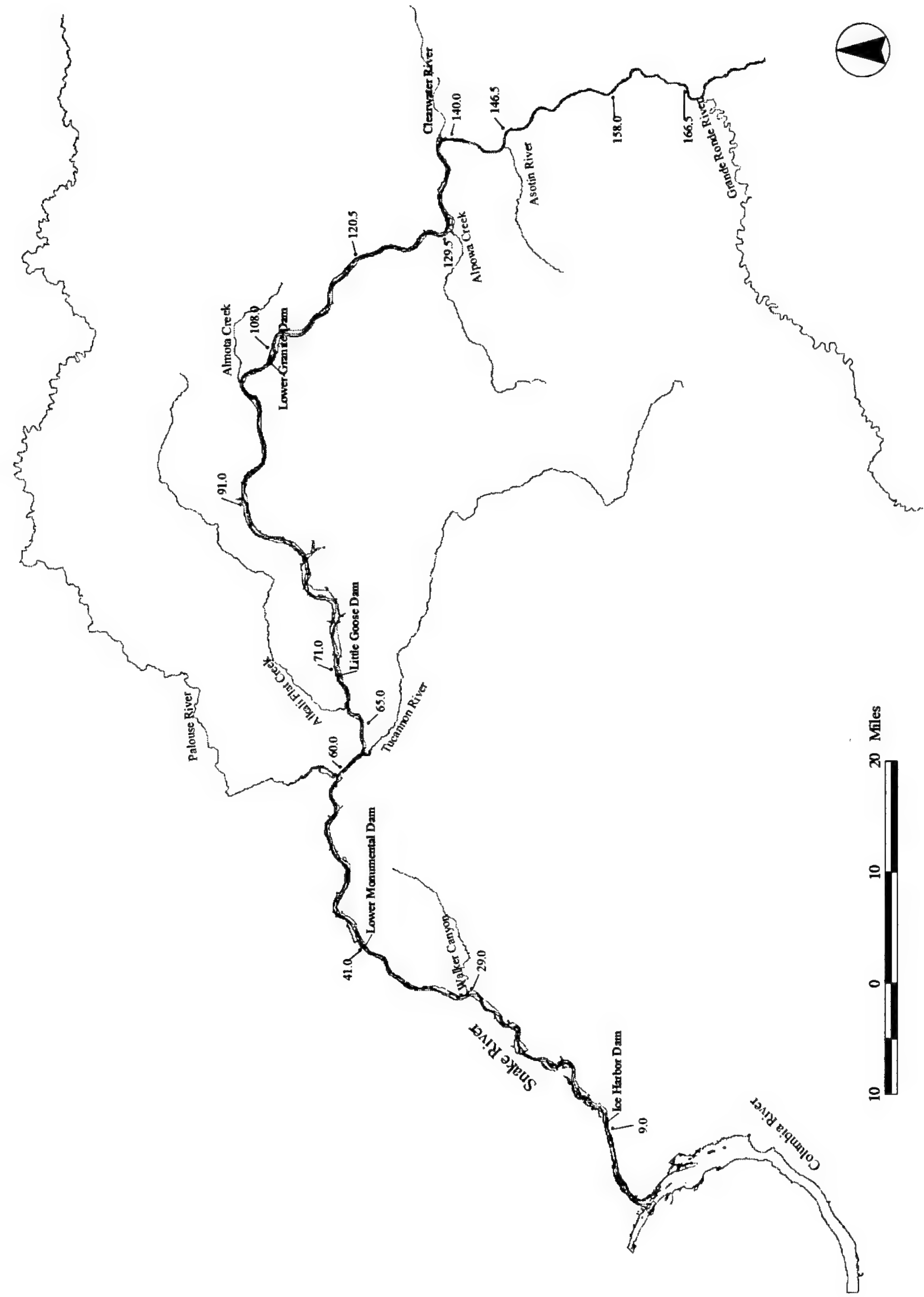


Figure 2-1. Analysis Area

3. Methods

Classification and characterization schemes of rivers based on morphology, process, and habitats are plentiful. The methods of interest for this analysis are those relating to descriptive morphology and indicators of river processes. The classification of river segments into unique groups is an endeavor dating back to the 19th century. Davis (1899) grouped rivers by their position in youthful, mature, and old landscapes. Leopold and Wolman (1957) investigated the range of channel patterns in planform; and arrived at groupings according to braided, meandering, and straight. Schumm (1963) provided an initial classification scheme based on sediment transport regime, which he later modified to include channel pattern and relative stability (Schumm, 1977). Kellerhals et al. (1976) proposed a classification system based on an extensive collection of river reach survey data for rivers in Alberta, Canada (Kellerhals et al., 1972). Their system incorporates channel patterns, the presence and type of depositional features, and consideration of valley features (i.e., confinement and geology). This was later modified by Church and Rood (1983) in an effort to compile many published river study data sets into a catalogue for the study of alluvial river channel regime. Montgomery and Buffington (1993) also incorporated coarse and fine scale parameters in their classification framework. They proposed a landscape and channel classification system for assessing watershed response to environmental change. In their system, channel reaches are classified as source, transport, or response relative to the initiation of change within the watershed. Any comprehensive assessment of channel morphology and processes should consider the influence of the valley on the river; as well as the planform, cross-sectional, and longitudinal dimensions of river reaches (Thorne, 1997). Rosgen's 1994 classification system fits this description, and has been described as possibly the most comprehensive system for classification yet devised (Hey, 1997). The characterization and classification system implemented in this study is a combination and modification of Kellerhals et al. (1976) and Rosgen (1996).

The methods described below address each of the three study objectives: 1) describe the physical characteristics and habitats of the pre-dam river; 2) quantify the geomorphic features that describe salmon production areas; and 3) evaluate changes in the flow regime under dam breaching.

3.1 Coarse Scale Geomorphic Characterization (Level 1)

Characterization of the lower Snake River began with an evaluation of the watershed-scale controlling factors of channel morphology (e.g., geology, physiography, longitudinal profile, and discharge). This scale was the initial level of assessment in an attempt to classify the 266 km (165-mile) study area into distinct geomorphic units. The objectives were to minimize the variability within each unit, maximize the variability between units, and classify the units based on parameters that would provide indicators of channel-forming processes, channel morphology at the reach scale, and reach scale response potential to change.

The coarse scale (level 1) classification was based on geology, physiography, and channel planform. Data for geologic features of the area were incorporated into a GIS. The data originated at a scale of 1:500,000 and contained descriptions of geologic formation, rock type, age, and major lithology (Johnson and Raines, 1996; Raines and Johnson, 1996). The lower Snake River valley was subsequently classified into three classes based on geological formations (unconsolidated sediments, bedrock, and mixed/unconsolidated bedrock), and compared with a 1:250,000 scale hard copy map

of geologic features in the analysis area (Schuster et al., 1997). The geologic features within 1.6 km (1 mile) of the river channel were used in the level 1 classification.

The assessment of physiography involved the evaluation of the river valley morphology as a whole. It involved an interpretation of structural controls and lithology, landforms, and fluvial processes. Primary attention was given to the relationship between the river channel and the valley walls, providing an indication of the lateral and vertical control the valley imposes on the river. Interpretation of these features and processes were based on models of landform that were incorporated into the GIS. Individual digital elevation models (DEMs), with a 30 meter cell resolution and a scale of 1:24,000, were combined into one DEM for the entire analysis area. The resulting DEM was subjected to a hillshading algorithm, which allows for easy visual distinction of topographical relief. A similar hillshaded DEM model was built for the river channel (bathymetry) and near-shore topography for the entire analysis area. That DEM was based on depth soundings taken during low flow periods in 1933 and 1934, which were mapped at 1:2,000 for the entire analysis area by the Corps. Near-shore topography up to several hundred feet in elevation was also mapped at 1:2,000. These data were incorporated into the GIS and transformed into a three-dimensional surface for producing the hillshaded DEM. The resulting DEMs were interpreted for the presence of different valley types (i.e., broad, gently-sloping valley walls vs. deep, confined, steep-sloped valley walls), structural containment by the valley walls, and fluvial processes (e.g., scour and fill) within the river channel. The physiographic interpretation resulted in two classes being used for the level 1 classification: confined and moderately confined. These two classes describe the degree of structural confinement of the channel within the valley walls. Confinement was generally indicated where the channel occupied the majority of the valley bottom, with little alternate bar (channel side bar) development.

Channel planform was the final parameter used in the level 1 classification. The 1:2,000 scale pre-dam Corps maps discussed earlier were incorporated into the GIS. The maps depict shoreline, islands, and bars at low flow. The level 1 classification included channel pattern (e.g., sinuosity) and depositional features (i.e., islands and bars). River sinuosity (P) is used to indicate how the river has adjusted its slope relative to the slope of its valley. For a given river segment, P was calculated as the ratio of river channel length to valley length (Richards, 1982).

Planform depositional features were incorporated into the level 1 classification by delineating river segments into two classes: islands or bars present, and islands or bars absent. Only genetic features (those constructed by the present-day river through the course of lateral shifting or flooding (Kellerhals et al., 1976; Kellerhals and Church, 1989)) were included in the classification. The term, "genetic features," is used differentiate them from terraces deposited during cataclysmic events (e.g., the Bonneville Flood) that were constructed at elevations exceeding present-day peak flood stages. Genetic features were interpreted from the pre-dam maps and hillshaded DEMs, based on their elevation relative to the water surface elevation.

The level 1 classification was completed by using GIS map overlay techniques based on data layers depicting geology, physiography, and channel planform. The data layers were combined to find the spatial relationship among the three characteristics.

3.2 Reach Scale Classification (Level 2)

Characterization of the lower Snake River at the reach scale was based on an analysis of hydraulic geometry and channel morphology at sampled cross sections. Hydraulics at each cross section were

simulated, using both one-dimensional (MASS1) and two-dimensional (MASS2) unsteady flow models developed at the Pacific Northwest National Laboratory (Richmond and Perkins, 1999). The MASS1 model was used to estimate cross-section averages of hydraulic parameters, while the MASS2 model was used to estimate depth-averaged hydraulic parameters in a horizontal plane (e.g., lateral variation in velocity). The physical basis for the cross sections was the pre-dam channel morphology data (i.e., bathymetry surface and planform characteristics) incorporated into the GIS from the 1934 Corps maps. A total of 338 cross sections, spaced 0.4 to 0.8 km (0.25 to 0.5 mile) apart, were placed in the 266-km (165-mile) study area for the MASS1 modeling. The MASS2 modeling results were extracted at cross sections spaced 0.16 km (0.1 mile) apart in order to identify fine-scale lateral and longitudinal variations in the hydraulic parameters. The models were run for flow scenarios approximating the 10-, 50-, and 90 percent exceedance discharges (Q10 = 3,157 cms (111,500 cfs), Q50 = 898 cms (31,710 cfs), Q90 = 472 cms (16,680 cfs), respectively) based on 67 years of mean monthly flow at Lower Granite Dam. At each cross section, MASS1 model outputs included average estimates of discharge, water surface elevation, velocity, thalweg elevation, cross-sectional area, and hydraulic radius. Three additional characteristics for each cross section were computed from these estimates: width to depth ratio (F), water surface slope (S), and entrenchment ratio (ER). The level 2 classification used F and S values based on the Q50 hydraulic results. The ER characteristic for the level 2 classification was based on the ratio of the top width for the Q10 flow (i.e., high flow) to the top width for the Q50 flow. The ER characteristic is used as an index of channel shape and entrenchment, where values approaching 1 indicate an entrenched channel capable of containing a high flow within its banks (Rosgen, 1996).

Channel substrate data were also incorporated into the level 2 classification. The 1934 Corps maps contained handwritten notations of substrate types for the river channel and shoreline. The notes are qualitative assessments of substrate type, and provide only a general idea of grain sizes and spatial distribution. Limitations encountered with these data include: 1) there are no spatial demarcations on the maps indicating spatial extent of substrate types; 2) different words are used to describe the same size classes (e.g., "gravel to 6 in" and "rocks to 6 in"); 3) substrate descriptions are often combined with no indication of dominance or relative abundance (e.g., "sand and gravel 1 to 8 inches"); and 4) substrate descriptions often describe more than one substrate class relative to the American Geophysical Union (AGU) grain size classification (Vanoni, 1975). For example, "gravel to 6 inches" would include all classes between very fine gravel (2 millimeters, .08 inches) and large cobble (152.4 millimeters, 6 inches). The handwritten notations of substrate type were incorporated into the GIS as point samples. The notes for each point sample were converted into one of five classes according to the appropriate AGU grain size classification (Table 3-1). Where the notes of grain sizes ranged over more than one AGU grain size classification, the median of that range was applied to that point. The sampling points were color coded according to the grain size class and plotted with the GIS. Areas of the river channel were subsequently interpreted as to the dominant and subdominant grain size class, and segments of the river were delineated accordingly. The qualitative nature of the substrate data led to a further reclassification by grouping grain size classes. For example, all sampling points in the cobble and gravel classes were grouped into one class without indication of dominance and subdominance (Table 3-2). A resulting substrate class was then assigned to each cross section.

The level 2 classification proceeded by assigning a value for each characteristic (D, F, S, ER) to each cross section. The definitions and categories for each characteristic are provided in Table 3-2.

Table 3-1. Grain Size Classification

Size Class	Grain Diameter (millimeters)
Bedrock	
Boulder	>256
Cobble	64-256
Gravel	2-64
Sand	0.0625 – 2

Table 3-2. Level 2 Characteristics

Level 2 Characteristic	Definition	Code
Substrate (*D*)	Bedrock/boulder Cobble/gravel Sand	*D*1 *D*34 *D*5
Width: Depth ratio (F)	Low to moderate, <20 Moderate to high, >=20	*F-* *F+*
Water surface slope (S) 50 percent exceedance flow	Low to moderate, <0.001 Moderate to high, >=0.001	*S-* *S+*
Entrenchment ratio (*ER*) Width of 10 percent to width of 50 percent exceedance flow	Entrenched, <1.4 Moderate, >=1.4	*ER-* *ER+*

Table 3-3. Example and Description of Level 2 Classification

Level 2 Class			*F_bi* D34 F+ S- ER-		
Characteristic:	F_bi	*D34*	*F+*	*S-*	*ER-*
Description:	See level 1 code	Dominated by cobble/gravel substrate	Moderately high width-to-depth ratio	Low-to-moderate water surface slope	Entrenched within the valley bottom

The level 2 class of a given cross section was determined by combining its level 1 class with its D, F, S, and ER values (see Table 3-3 for an example).

3.3 Additional Hydraulic and Geomorphic Characteristics

Hydraulic parameters and indices of channel shape were also summarized for each cross section. The Q_{50} flow was used to calculate mean depth, width, and velocity, width to depth ratio (*F*), maximum depth to mean depth ratio (d_{max}/d), and unit stream power (•). Stream power per unit bed area was calculated as:

$$T = pgdvs_e$$

where *T* is the fluid density, *g* is gravitational acceleration, *d* is depth, *v* is velocity, and s_e is the energy slope approximated by the water surface slope.

Additional spatial assessment of pool, run, and riffle/rapid habitat features was completed based on hydraulic modeling results. Typical parameters used include combinations of velocity/depth ratio, Froude number, and water surface slope. These parameters are typically calibrated to visual

assessments of pool, run, and riffle habitat types made during field visits. Once calibrated, the parameters are used to predict the quantity and spatial composition of the habitat features (Jowett, 1993). The physical criteria used to delineate habitat features (e.g., velocity/depth ratio <1.24 indicates pool habitat) are specific to the river for which the criteria were developed, and are generally not transferable to different rivers. This required us to correlate visual estimates of pool, riffle, run habitat from pre-dam maps with hydraulic parameters estimated through modeling. The spatial assessment of pool, run, and riffle/rapid habitats for the lower Snake River was based on the calculated velocity/depth ratio for the Q_{50} flow. The linear (upstream/downstream) extent of some rapids were depicted on the 1934 pre-dam maps and were digitized into a GIS data layer. Pool, riffle, or other similar habitat types were not depicted on the 1934 pre-dam maps, and therefore could not be used for correlating hydraulic estimates. The extent of pre-dam rapids was plotted on the GIS on top of the data layer depicting velocity/depth ratio. This map overlay was used to determine the velocity/depth criteria distinguishing rapids from other habitats. Criteria distinguishing pool and run habitats were estimated based on an interpretation of the remaining velocity/depth ratios and channel morphology. The habitat criteria are based on the following velocity/depth ratios: pool 0.0—0.50, run 0.51—1.20, riffle/rapid >1.20.

3.4 Geomorphic Features and Salmon Production Areas

Prior to hydroelectric development in the lower Snake River, no comprehensive surveys of any general spawning area for fall chinook or steelhead were ever conducted, as far as the author knows. During the hydroelectric development period (beginning in the 1950s), spawning surveys were initiated to provide baseline information on the distribution and numbers of salmon redds present prior to construction of planned hydro projects (Battelle and USGS, 1999). The locations of pre-dam spawning areas in the lower Snake River were compiled from Fulton (1968) and Battelle and USGS (1999). These data sets provide the best quantitative measure of habitat used, however, it is unknown whether these same habitats were used by salmonids to the same extent before Europeans settled in the Pacific Northwest.

All quantitative data sets for fall chinook spawning locations were incorporated into the GIS through the use of dynamic segmentation. These data sets were built as linear event tables containing locational information (e.g., from river km, to river km), attribute data, and database keys linking to the reference source for the attribute data. The event tables were then linked to their location in the lower Snake River through the use of 1:100,000 scale Pacific Northwest River Reach Files (PNW RRF) obtained from the USGS and StreamNet. These files include GIS data layers containing line segments that represent the channel midline.

We used the geology and planform data layers to quantify the geologic composition and availability of depositional features along the lower Snake River. The 1:100,000 scale PNW RRF were segmented into 500 m (1640 ft) linear sections and used as the base layer for delineating geologic and depositional features. The delineation of these features correlated spatially with the delineation of fall chinook spawning locations described earlier.

The geologic composition of the right and left bank (facing downriver) for each 500 m (1640 ft) segment was estimated through the use of nearest neighbor analysis in the GIS. Each 500 m (1640 ft) segment was assigned the geologic attributes (geologic formation, rock type, age, major lithology, and bedrock/unconsolidated classification) of the nearest right-bank and left-bank geologic unit. A composite geologic typing of each 500 m (1640 ft) segment was calculated by

averaging the right-bank and left bank bedrock/unconsolidated classification. Thus, each 500 m (1640 ft) segment could be one of three types: 100 percent unconsolidated, 50/50 unconsolidated /bedrock, 100 percent bedrock. The same composite geologic typing was completed for longer contiguous river sections as well (e.g., 32 km [20 mi]) spawning section), resulting in different percentages of geologic composition for these sections as a whole. Planform depositional features (bars and islands) were interpreted from planform GIS data layers. The data layers used included those depicting right- and left-bank shorelines, cutoff channels, islands, and near-shore topography (contour lines and hillshaded DEMs). Depositional features were incorporated into the analysis by delineating each 500 m (1640 ft) segment into one of three classes: islands or bars present, islands or bars absent, and unknown. Only genetic features were included in the classification. A composite depositional typing for contiguous river sections (e.g., 32 km [20 mi] spawning section) was calculated by determining the proportion of a given contiguous section classified as depositional features present, absent, and unknown.

Redd density data for fall chinook spawning in the Columbia and Snake rivers was used to evaluate the relationship between the geomorphic features described above and spawning areas (Battelle and USGS, 1999). These geomorphic features have previously been shown to be important for describing fall chinook spawning areas (Dauble and Geist, in press). Based on the relationship between redd densities and geomorphic features we created a geomorphic spawning habitat model where segments of river were considered usable if they contained greater than 50 percent unconsolidated sediment, contained bars and/or islands, and were less than 0.0005 in longitudinal gradient. River segments that met these criteria were considered suitable fall chinook salmon production areas while those that failed to meet all the criteria were considered unsuitable spawning habitat.

3.5 Flow Regime and Sediment Transport

Flow records analyzed for this study represent discharge of the Snake River near the upriver end of the study area and downriver of the confluence with the Clearwater River. Daily discharge records for the period January 1, 1929 through December 31, 1973 were obtained from the USGS gage (13343500) near Clarkston, Washington. This gage was discontinued after December 31, 1973. To estimate daily discharge at the same location after this period, we summed the discharges from three different gages approximating the total aggregate flow to that location. Daily discharge records for the period January 1, 1974 through June 30, 1996 were obtained from the USGS gages on the Snake River near Anatone (13334300), on Asotin Creek near Asotin, Washington (13334700), and on the Clearwater River at Spaulding, Washington (13342500). The discharge record for Asotin Creek ends at June 30, 1996, but was extended through linear regression with the USGS gage on the Grande Ronde River (13333000) to be coincident with the time steps of the other gages. Total discharge for the period July 1, 1996 through September 30, 1998 was estimated by summing the daily records from the Anatone gage, the extended Asotin Creek records, and the Spaulding gage.

The flow regime for the time period prior to major hydroelectric development (pre-major storage, 1929-1958) was assumed to be indicative of the flow regimes that shaped and maintained the river during that period. The flow regime after major hydroelectric development (post-major storage, 1959-1998) was assumed to be indicative of the flow regimes that will persist into the future, even after modification of the four lower Snake River dams. The constructed flow record represents discharge upriver of the four lower Snake River dams and downriver from the hydroelectric dams and storage reservoirs that will be unaffected by modifications to the lower Snake River dams.

The limited availability of present substrate conditions in the entire lower Snake River inhibits the estimation of sediment transport following dam breaching. The most data available is for that area upriver of Lower Granite Dam. Estimates of the time required to remove sediment accumulated in Lower Granite reservoir were based on estimates of available sediment and one-dimensional hydrodynamic modeling simulations (see Hanrahan et al., 1998, for details).

This page is intentionally left blank.

4. Results and Discussion

4.1 Coarse Scale Geomorphic Characterization (Level 1)

When viewed in planform the lower Snake River exhibits a meandering course, but geomorphologically it is a straight or slightly sinuous river (P <1.2). The river possesses the characteristics of passive meandering, where the planform pattern is imposed by the local landform (Richards, 1982; Thorne, 1997). This characteristic is distinct from completely self-formed alluvial channels that are actively and freely forming the valley bottom (active meandering). Because of the homogeneity of low P values throughout the study area, sinuosity was not a primary determining factor in the coarse scale classification.

The lower Snake River was delineated into three classes, which are described in Table 4-1. The analysis area contains 14 percent of the C_{bi} class, 26 percent of the F class, and 60 percent of the F_{bi} class (Figures 4-1 through 4-3). Most alluvial or partially-alluvial reaches of the lower Snake River fall under the level-1 classifications of C_{bi} and F_{bi}. Bedrock-confined and colluvial reaches are found mostly in the areas of level-1 F classifications. Two general areas within the lower Snake River are classified as C_{bi}: from the mouth upriver to approximately RM 16.0, and near the confluence with the Clearwater River, from RM 134 to 142. For comparison sake, the Hanford Reach of the Columbia River is also classified as C_{bi} when using the same classification methods used in this study. Areas classified as F_{bi} are sporadic, with one large contiguous section extending from approximately RM 66 to 120. The distribution of areas classified as F is similarly patchy, although one large section extends from approximately RM 44 to 66. Within each level-1 class, a diversity of channel forms was classified at the cross section scale (level 2).

Table 4-1. Level 1 Classification

Level 1 Code	Description
C_bi	The major lithology is dominated by unconsolidated sedimentary rocks and deposits. The river channel is moderately confined by the valley/canyon walls; indicating it is neither totally confined nor totally unconfined. Bars and/or islands are present.
F_bi	The major lithology is a mix of unconsolidated sedimentary rocks/deposits and basalt bedrock. The river channel is moderately confined by the valley/canyon walls; indicating it is neither totally confined nor totally unconfined. Bars and/or islands are present.
F	The major lithology is a mix of unconsolidated sedimentary rocks/deposits and basalt bedrock. The river channel is highly confined by the valley/canyon walls, and occupies almost the entire valley bottom. Bars and/or islands are absent.

4.2 Reach Scale Classification (Level 2)

Although geomorphologically straight rivers such as the lower Snake River do not follow an actively sinuous path, many do possess a regularly meandering thalweg and filament of maximum velocity (Richards, 1982; Thorne, 1997). Results from the 2-dimensional hydrodynamic modeling (MASS2) indicate a meandering thalweg (Figure 4-4) and filament of maximum velocity (Figure 4-5). These characteristics are closely related to vertical oscillations in bedforms (pool/riffle), which are in turn a dynamic response to non-uniform velocity, boundary shear stress, and sediment transport (Thorne, 1997). These reach level characteristics were further evaluated through the analysis of hydraulic geometry and longitudinal profiles in the reach scale classification.

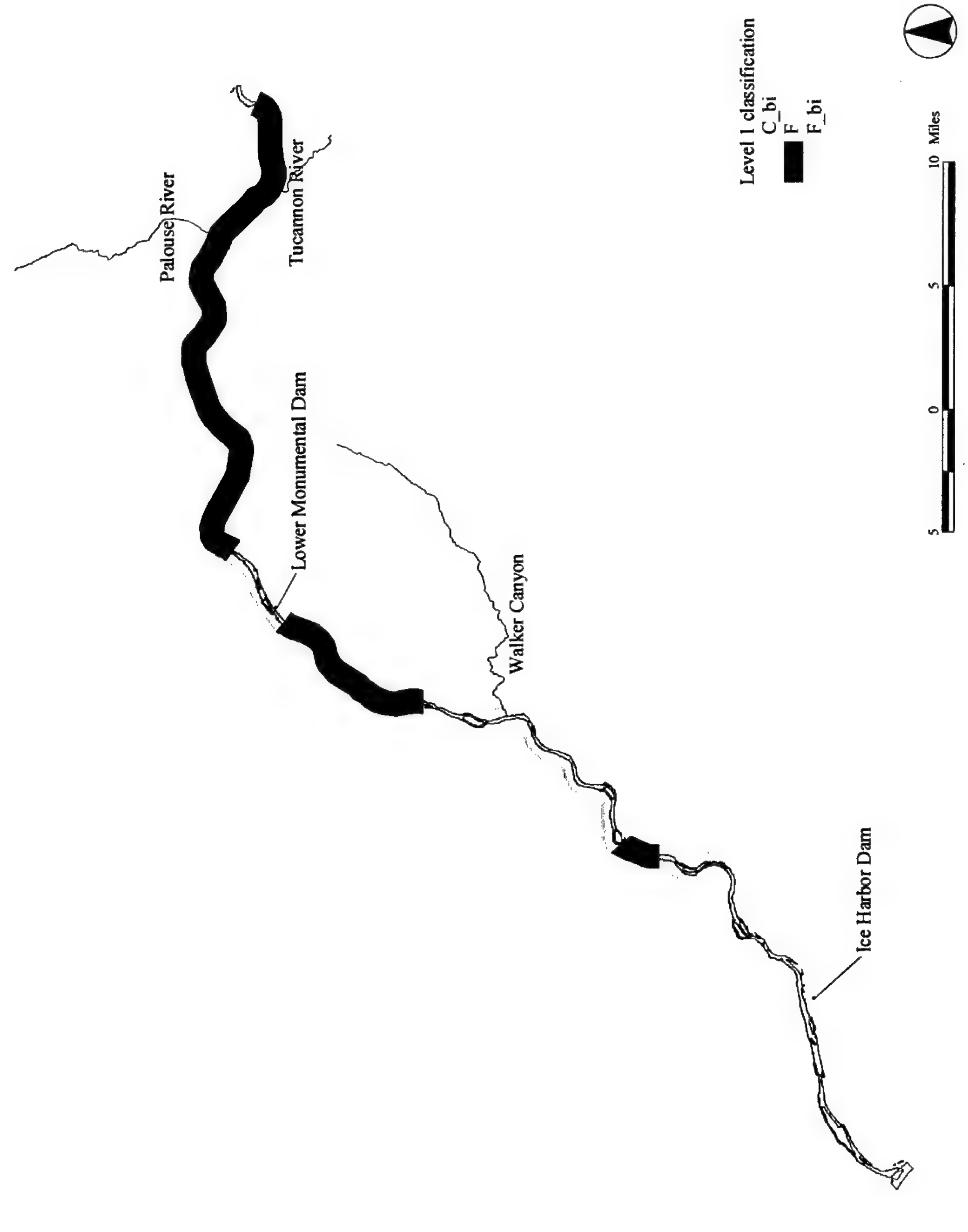


Figure 4-1. Level 1 Classification, Ice Harbor to Tucannon River

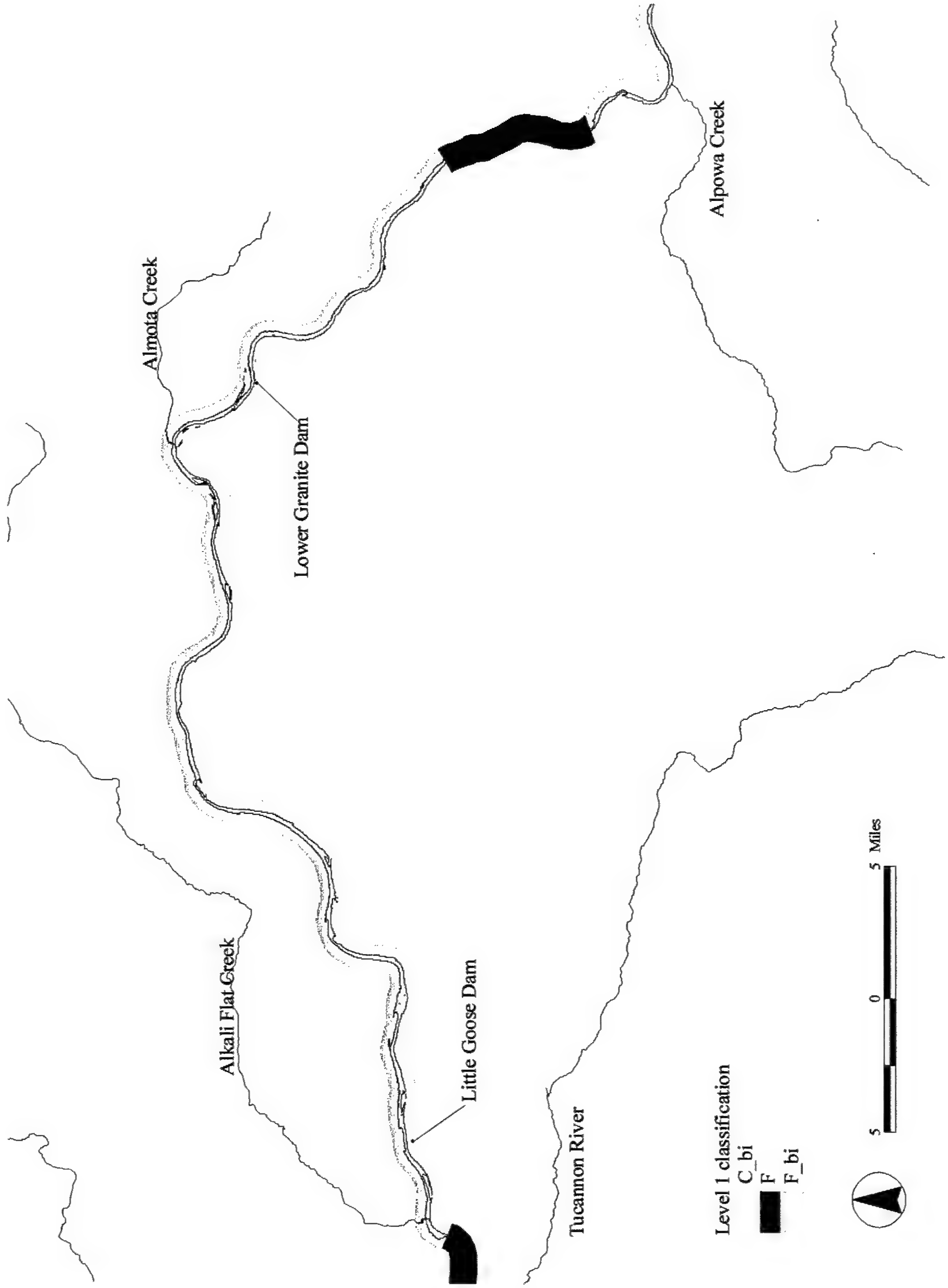


Figure 4-2. Level 1 Classification, Tucannon River to Alpowa Creek

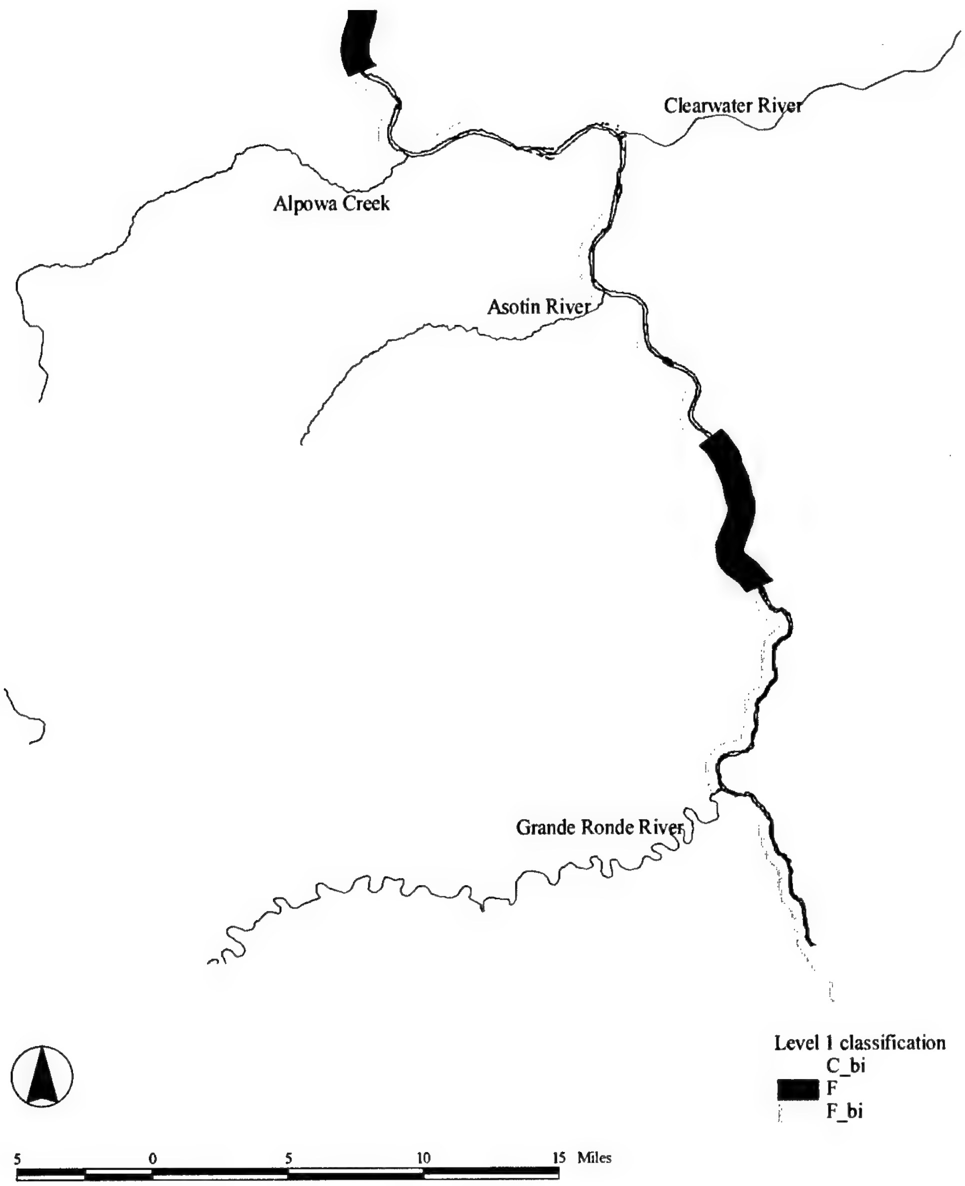


Figure 4-3. Level 1 Classification, Alpowa Creek to Grande Ronde River

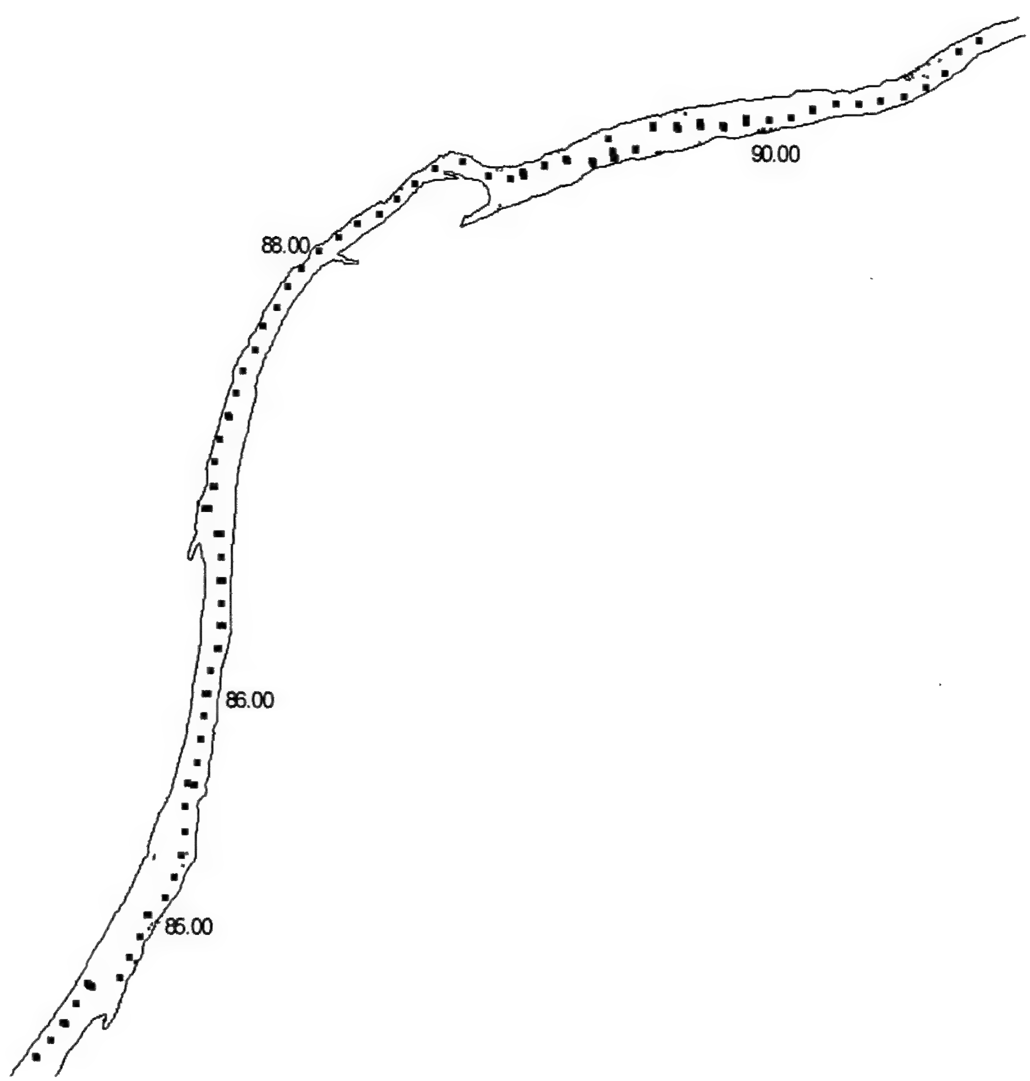


Figure 4-4. Example of Meandering Thalweg

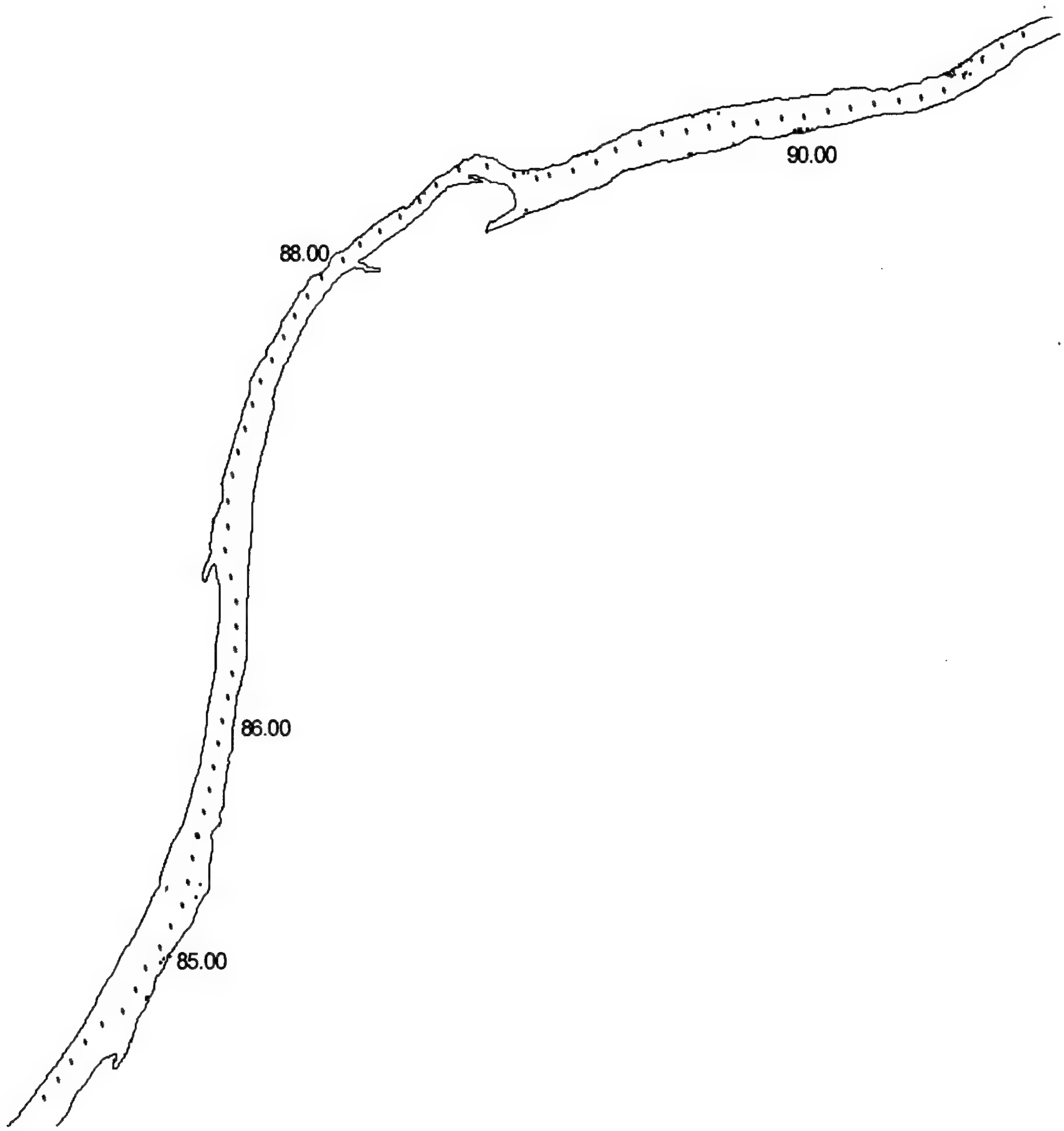


Figure 4-5. **Example of Meandering Filament of Maximum Velocity**

The level 2 classification resulted in 20 classes, including 4 within the level 1 class C_{bi}, 8 within F_{bi}, and 8 within F (Table 4-2). Again, most alluvial or partially-alluvial reaches fall under the level 1 classes, C_{bi} and F_{bi}, while bedrock-confined and colluvial reaches are found mostly in the areas of level 1 F classifications. The level 2 class $F_{bi}7$ represents the most common reach type, followed by F6, $C_{bi}4$, and $F_{bi}5$ (Table 4-3 and Figure 4-6). Level 2 classifications for each cross section are depicted spatially on Figures 4-7, 4-8, and 4-9, according to level 1 class C_{bi}, F_{bi}, and F, respectively. On a dam-by-dam basis, the section between Little Goose Dam and Lower Granite Dam contains the largest number and percentage (100 percent) of partially-alluvial reaches (Table 4-4). Similarly, the section upriver of Lower Granite Dam contains a considerable percentage of partially-alluvial (62 percent) and alluvial (20 percent) reaches (Table 4-4), particularly near the confluence with the Clearwater River.

Table 4-2. Level 2 Classification Descriptions by Level 1 Classification

Level 1	Level 2	Level 2 Code	Description
C_bi			The major lithology is dominated by unconsolidated sedimentary rocks and deposits. The river channel is moderately confined by the valley/canyon walls, indicating it is neither totally confined nor totally unconfined. Bars and/or islands are present.
	C_bi D34 F+ S+ ER+	C_bi1	Cobble/gravel substrate, moderate to high F, moderate to high slope, moderately entrenched.
	C_bi D34 F+ S+ ER-	C_bi2	Cobble/gravel substrate, moderate to high F, moderate to high slope, entrenched.
	C_bi D34 F+ S- ER+	C_bi3	Cobble/gravel substrate, moderate to high F, low slope, moderately entrenched.
	C_bi D34 F+ S- ER-	C_bi4	Cobble/gravel substrate, moderate to high F, low slope, entrenched.
F_bi			The major lithology is a mix of unconsolidated sedimentary rocks/deposits and basalt bedrock. The river channel is moderately confined by the valley/canyon walls, indicating it is neither totally confined nor totally unconfined. Bars and/or islands are present.
	F_bi D1 F+ S+ ER-	F_bi1	Bedrock channelbed, moderate to high F, moderate to high slope, entrenched.
	F_bi D1 F+ S- ER+	F_bi2	Bedrock channelbed, moderate to high F, low slope, moderately entrenched.
	F_bi D1 F+ S- ER-	F_bi3	Bedrock channelbed, moderate to high F, low slope, entrenched.
	F_bi D34 F+ S+ ER+	F_bi4	Cobble/gravel substrate, moderate to high F, moderate to high slope, moderately entrenched.
	F_bi D34 F+ S+ ER-	F_bi5	Cobble/gravel substrate, moderate to high F, moderate to high slope, entrenched.
	F_bi D34 F+ S- ER+	F_bi6	Cobble/gravel substrate, moderate to high F, low slope, moderately entrenched.
	F_bi D34 F+ S- ER-	F_bi7	Cobble/gravel substrate, moderate to high F, low slope, entrenched.
	F_bi D34 F- S- ER-	F_bi8	Cobble/gravel substrate, low F, low slope, entrenched.
F			The major lithology is a mix of unconsolidated sedimentary rocks/deposits and basalt bedrock. The river channel is highly confined by the valley/canyon walls, and occupies almost the entire valley bottom. Bars and/or islands are absent.
	F D1 F+ S+ ER-	F1	Bedrock channelbed, moderate to high *F*, moderate to high slope, entrenched.
	F D1 F+ S- ER+	F2	Bedrock channelbed, moderate to high *F*, low slope, moderately entrenched.
	F D1 F+ S- ER-	F3	Bedrock channelbed, moderate to high *F*, low slope, entrenched.
	F D34 F+ S+ ER-	F4	Cobble/gravel substrate, moderate to high *F*, moderate to high slope, entrenched.
	F D34 F+ S- ER+	F5	Cobble/gravel substrate, moderate to high *F*, low slope, moderately entrenched.
	F D34 F+ S- ER-	F6	Cobble/gravel substrate, moderate to high *F*, low slope, entrenched.
	F D34 F- S- ER+	F7	Cobble/gravel substrate, low *F*, low slope, moderately entrenched.
	F D34 F- S- ER-	F8	Cobble/gravel substrate, low *F*, low slope, entrenched.

Table 4-3. Level 2 Classifications as Percent of Lower Snake River

Level 2 Classification	Percent of Total
F_bI7	39.3
F6	18.9
C_bi4	10.7
F_bI5	8.6
F_bI6	8.0
F_bI4	2.7
F4	2.7
C_bi3	2.1
F1	1.8
F5	1.2
C_bi2	0.9
F3	0.6
C_bi1	0.3
F_bi1	0.3
F_bi2	0.3
F_bi3	0.3
F_bi8	0.3
F2	0.3
F7	0.3
F8	0.3

Table 4-4. Level 2 Classifications as Percent of Lower Snake River Segments

	Percent of Cross Section in Each Segment				
Level 2 Class	Mouth to Ice Harbor	Ice Harbor to Lower Monumental	Lower Monumental to Little Goose	Little Goose to Lower Granite	Upriver of Lower Granite
C_bi1	0.0	0.0	0.0	0.0	2.4
C_bi2	0.0	0.0	0.0	0.0	3.5
C_bi3	0.0	0.0	0.0	0.0	8.2
C_bi4	100.0	18.8	0.0	0.0	5.9
F1	0.0	0.0	8.3	0.0	1.2
F2	0.0	0.0	1.7	0.0	0.0
F3	0.0	0.0	3.3	0.0	0.0
F4	0.0	4.7	10.0	0.0	0.0
F5	0.0	0.0	5.0	0.0	0.0
F6	0.0	21.9	45.0	0.0	12.9
F7	0.0	0.0	1.7	0.0	0.0
F8	0.0	1.6	0.0	0.0	0.0
F_bi1	0.0	0.0	0.0	0.0	1.2
F_bi2	0.0	0.0	0.0	0.0	1.2
F_bi3	0.0	0.0	0.0	0.0	1.2
F_bi4	0.0	0.0	0.0	6.7	2.4
F_bi5	0.0	14.1	0.0	10.7	8.2
F_bi6	0.0	12.5	1.7	14.7	5.9
F_bi7	0.0	26.6	23.3	68.0	45.9
F_bi8	0.0	0.0	0.0	0.0	0.0
Total	100.0	100.0	100.0	100.0	100.0

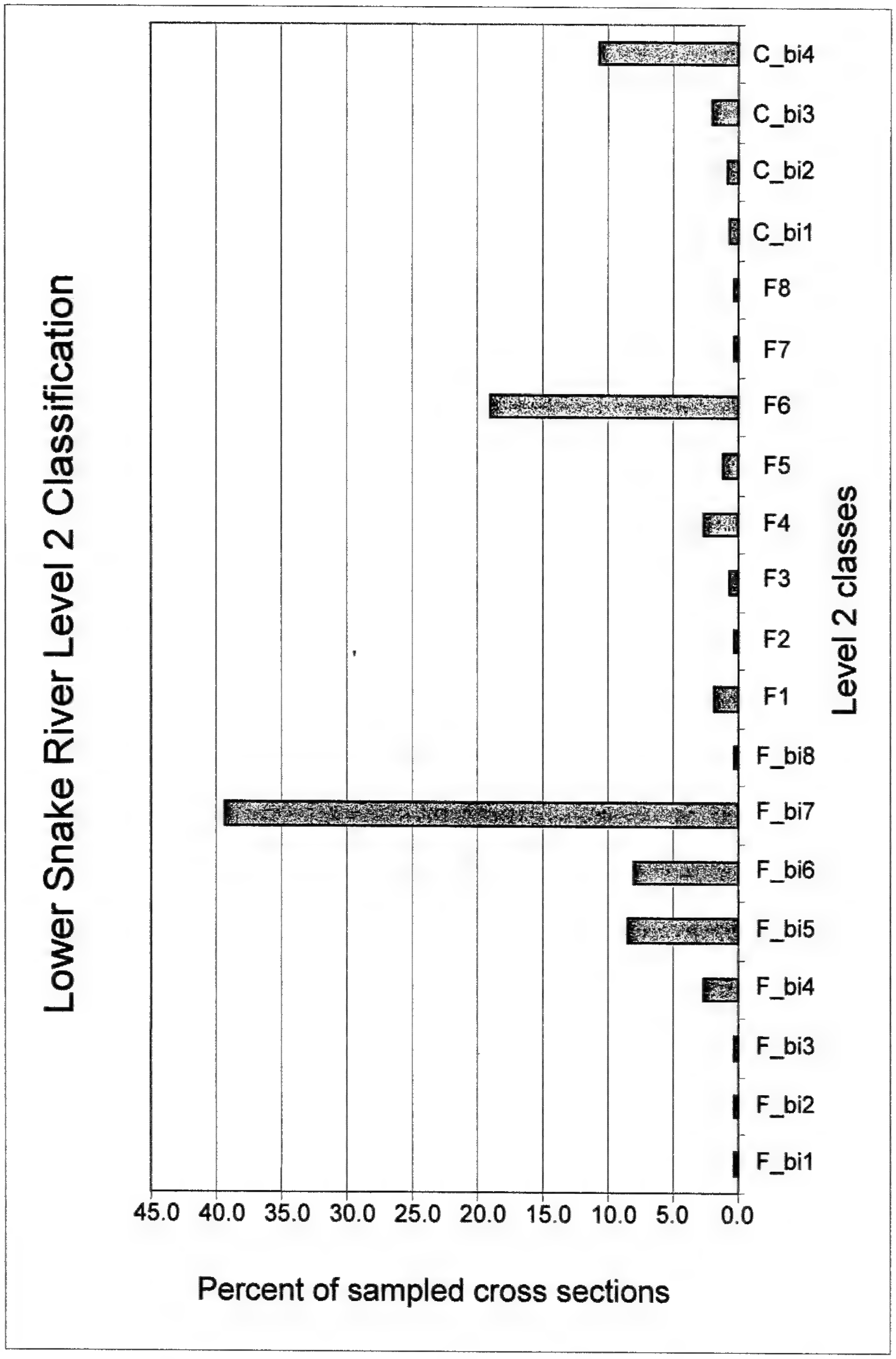


Figure 4-6. Level 2 Classifications as a Percent of the Lower Snake River

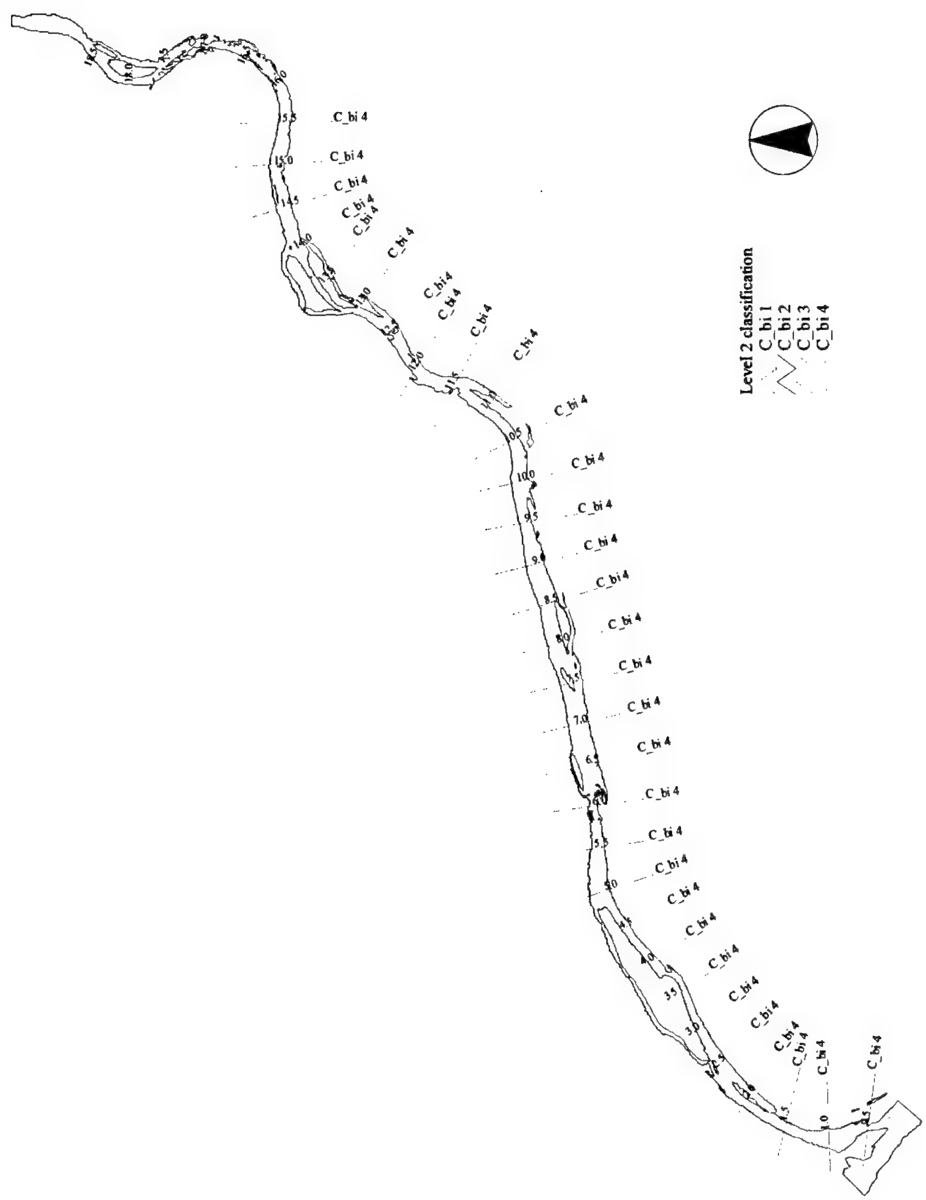


Figure 4-7. Level 2 C_{bi} Classification

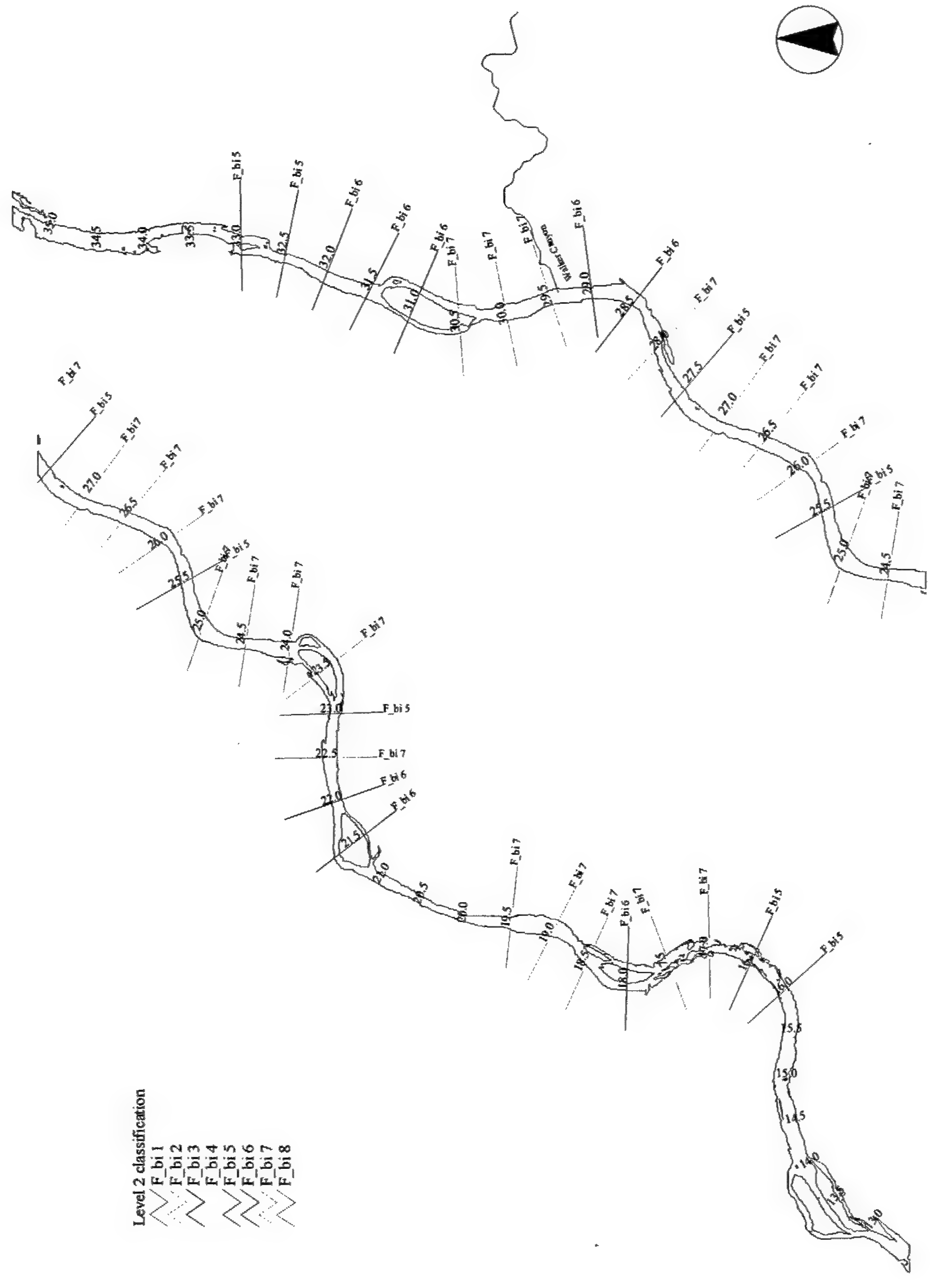


Figure 4-8. Level 2 F_{bi} Classification

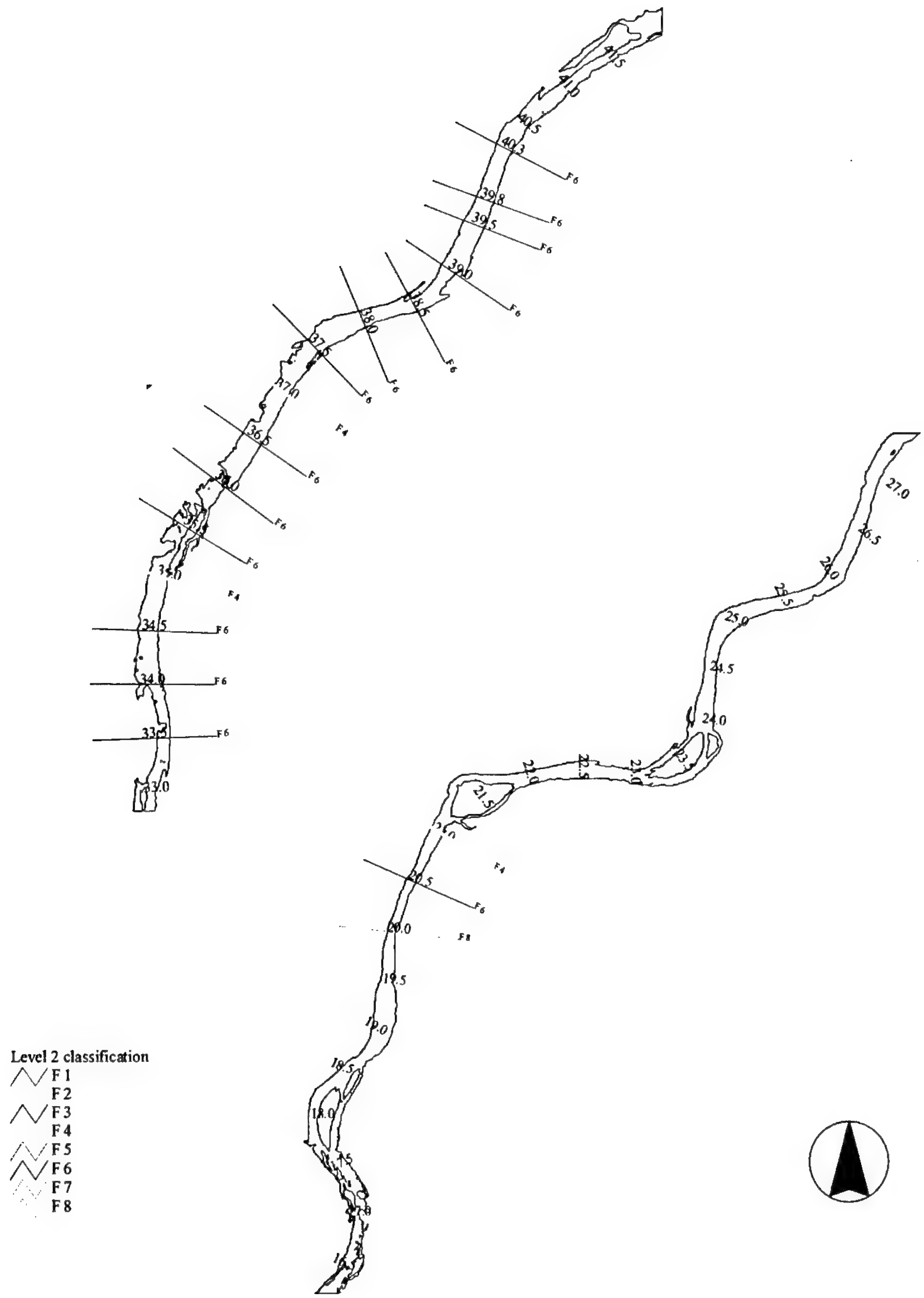


Figure 4-9. Level 2 F Classification

4.3 Additional Hydraulic and Geomorphic Characteristics

Mean velocity and mean depth for the Q50 flow provide an indication of hydraulic conditions from cross section to cross section (Figure 4-10), including indications of pools and riffles. Unit stream power is a hydraulic parameter often used to describe a river's ability to transport sediment and perform geomorphic work (Bagnold, 1977; Richards, 1982; Thorne, 1997). Stream power per unit bed area (T) ranges from approximately 0 to 150 Watts m-2, oscillating in magnitude between river reaches (e.g., Figure 4-11). The oscillations in T; closely match the oscillations of the longitudinal bedform profile. When plotted with the water surface elevation at cross sections spaced 0.16 km (0.1 mi) apart, the longitudinal bedform profile is indicative of alternating pool/riffle channel morphology (Figure 4-12). Riffle spacing in straight alluvial rivers has been described as being fairly constant—between 5 to 7 channel widths apart (Leopold et al., 1964). Research on gravel- and cobble-bed rivers in England found a similar pattern, with riffle spacing ranging from 4 to 10 channel widths in length (Hey and Thorne, 1986). In many segments of the study area the riffle spacing ranges from 4 to 10 channel widths in length (Figure 4-12). This characteristic of non-uniform bed topography in a straight alluvial channel is indicative of sufficiently widely graded bed material such that selective entrainment, transport, and deposition produces systematic sorting of grain sizes between scour pools and riffle bars (Thorne, 1997).

Based on velocity:depth criteria given earlier, the pre-dam channel morphology and the Q_{50} flow, the lower Snake River contained 4,060 hectares (ha) (10,032 acres) of pool habitat, 1,792 ha (4 ,428 acres) of run habitat, and 279 ha (689 acres) of riffle/rapid habitat (e.g., Figure 4-13). On a dam-by-dam basis, the section upriver of Lower Granite Dam contains the greatest percentage (70.5 percent) of pool habitat (Table 4-5). The section between Little Goose Dam and Lower Granite Dam contains the greatest surface area of pool habitat (970 ha [2397 acres]; 64 percent), while the section between Lower Monument Dam and Little Goose Dam is characterized by more riffle/rapid and run habitat (Table 4-5). These habitat features are very generalized, as there are many variations within a particular habitat class (e.g., mid-channel pool, backwater pool). Even on the rivers where the criteria were calibrated, correct classification of habitat features is only moderately accurate. For example, in a study with extensive field-calibrated data, Jowett (1993) was only able to correctly classify 65 percent of the habitats. Additionally, the amount of pool habitat downriver of Ice Harbor Dam may be overestimated because the hydraulic model incorporates the reservoir elevation backwater effects near the Columbia River confluence caused by McNary Dam.

The cross sectional form of natural channels are characteristically irregular and locally variable (Knighton, 1984). The width to depth ratio (F) is an important indicator of the distribution of available energy within a channel, and the ability of various discharges to move sediment (Rosgen, 1996). Relatively high F values such as those in the pre-dam lower Snake River (Figure 4-12) are often indicators of channel instability. This indication is based on the fact that channels with high F values distribute energy and stress on the near-bank region (Rosgen, 1996). Whether a reach with high F values is indeed unstable depends on the erosion resistance characteristics of the bank material. Bank materials in the lower Snake River are predominantly highly erosion resistant.

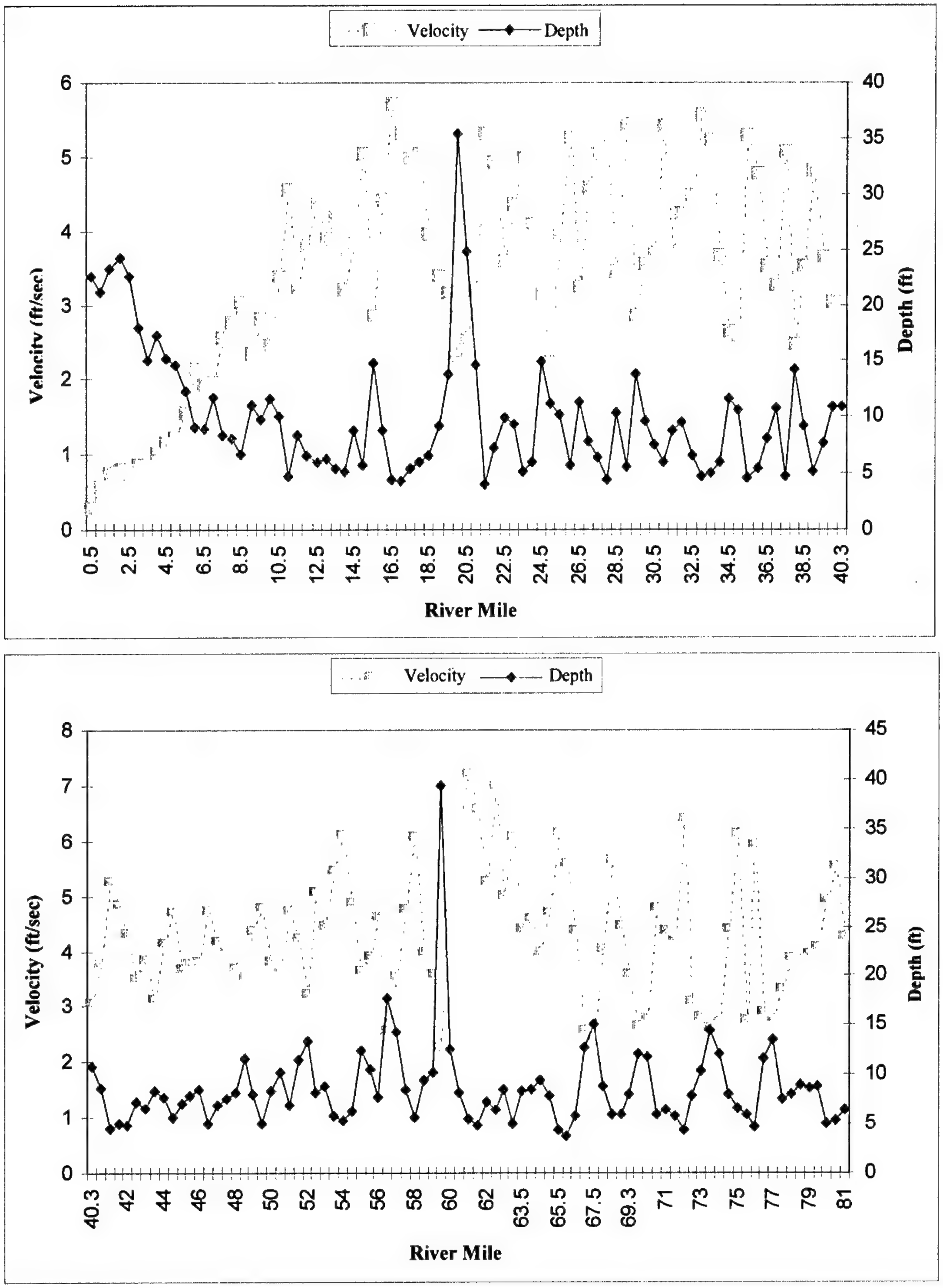
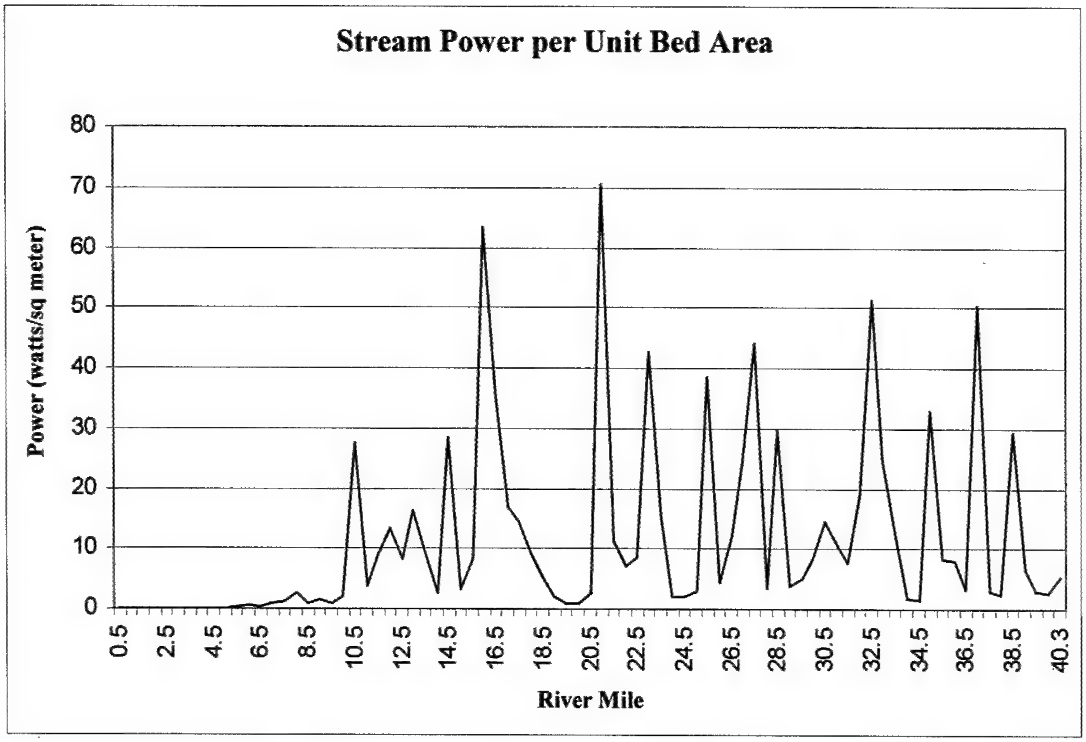


Figure 4-10. Mean Velocity and Mean Depth at Each Cross Section for Q_{50} Flow



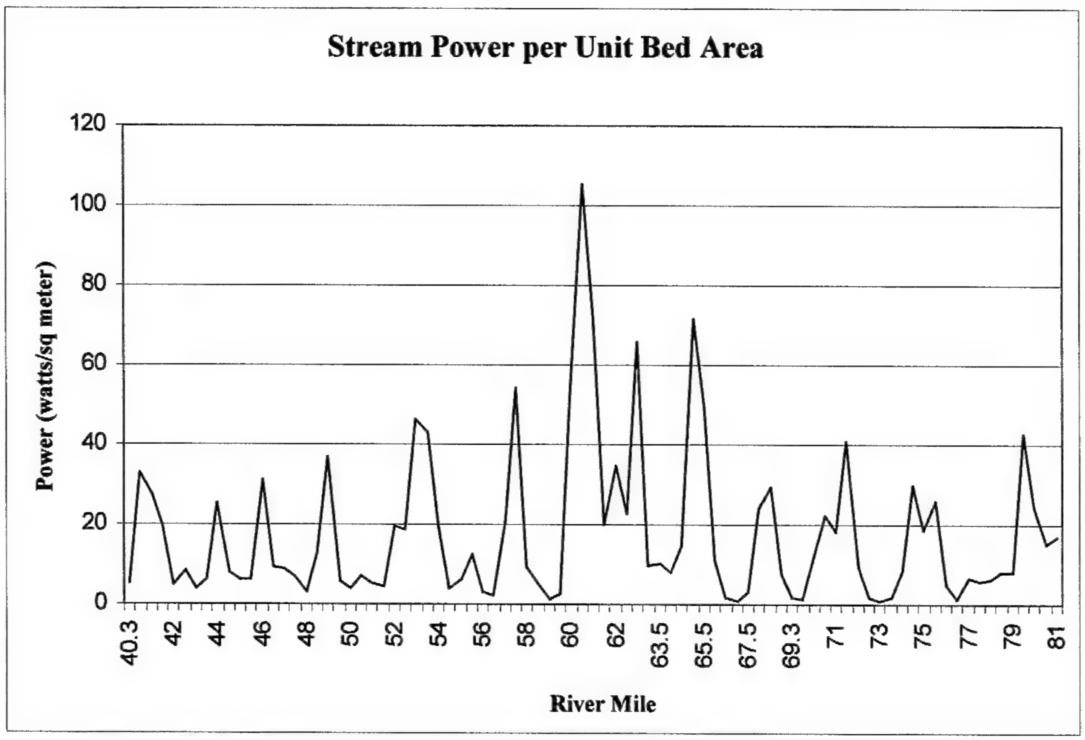
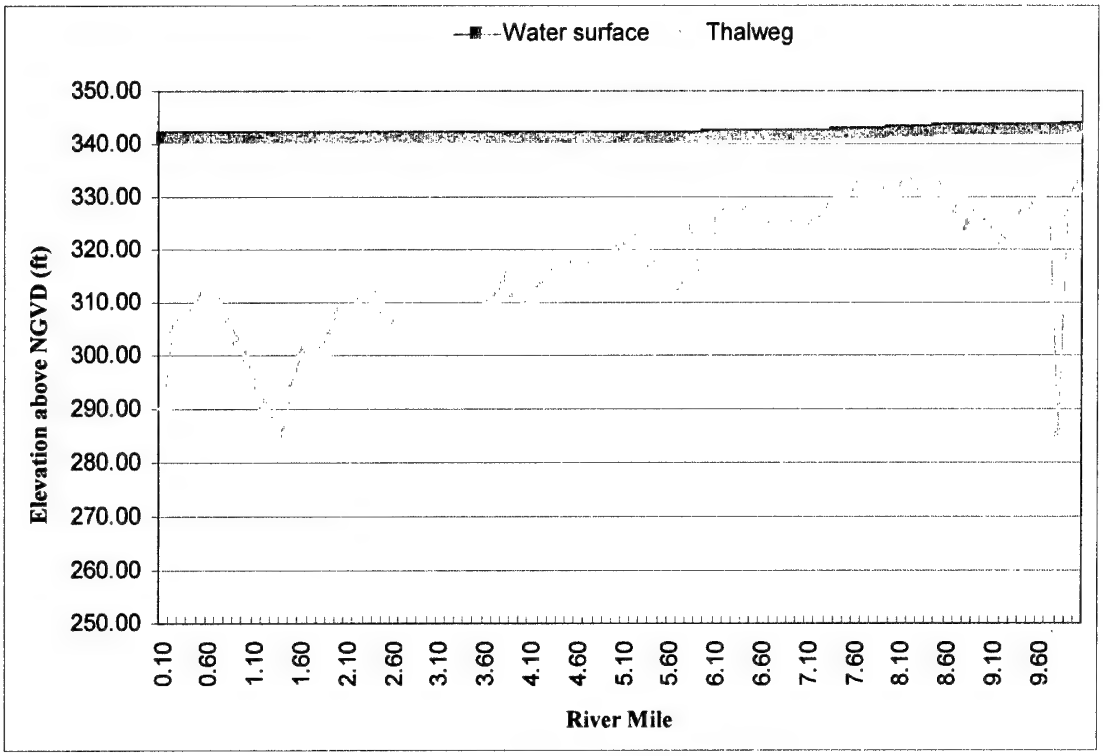


Figure 4-11. Stream Power at Each Cross Section for Q_{50} Flow



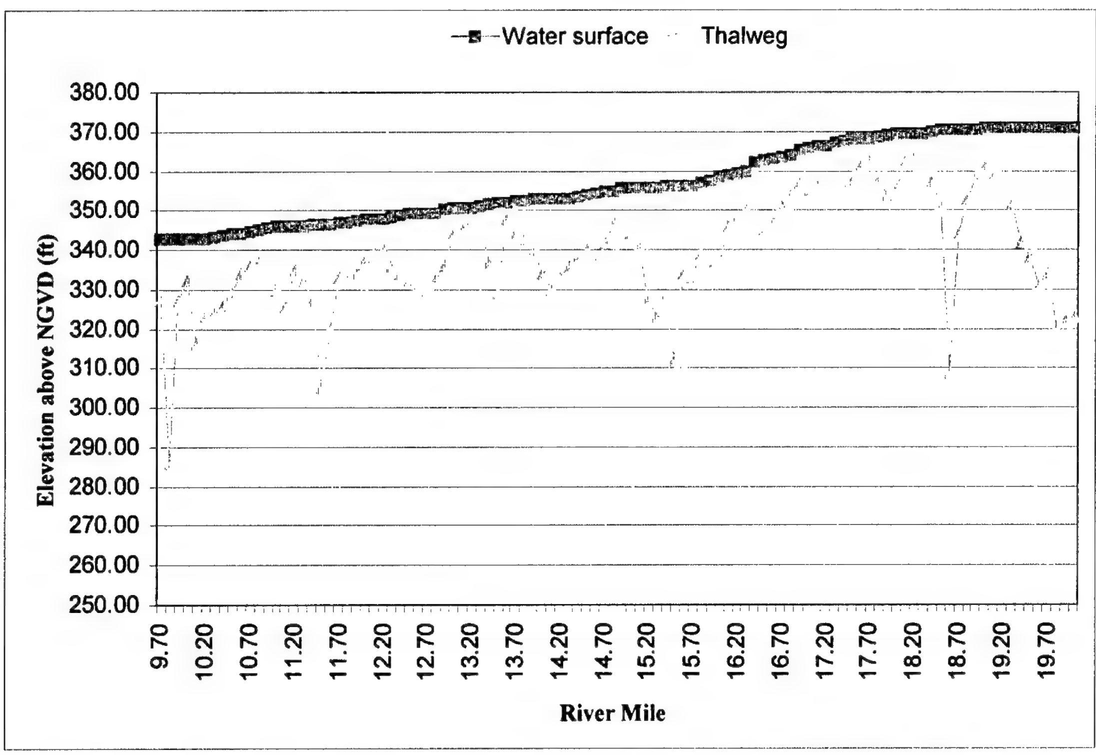


Figure 4-12. Longitudinal Profile of Water Surface and Thalweg Elevations for Q_{90} Flow

Note: NGVD=National Geodetic Vertical Datum

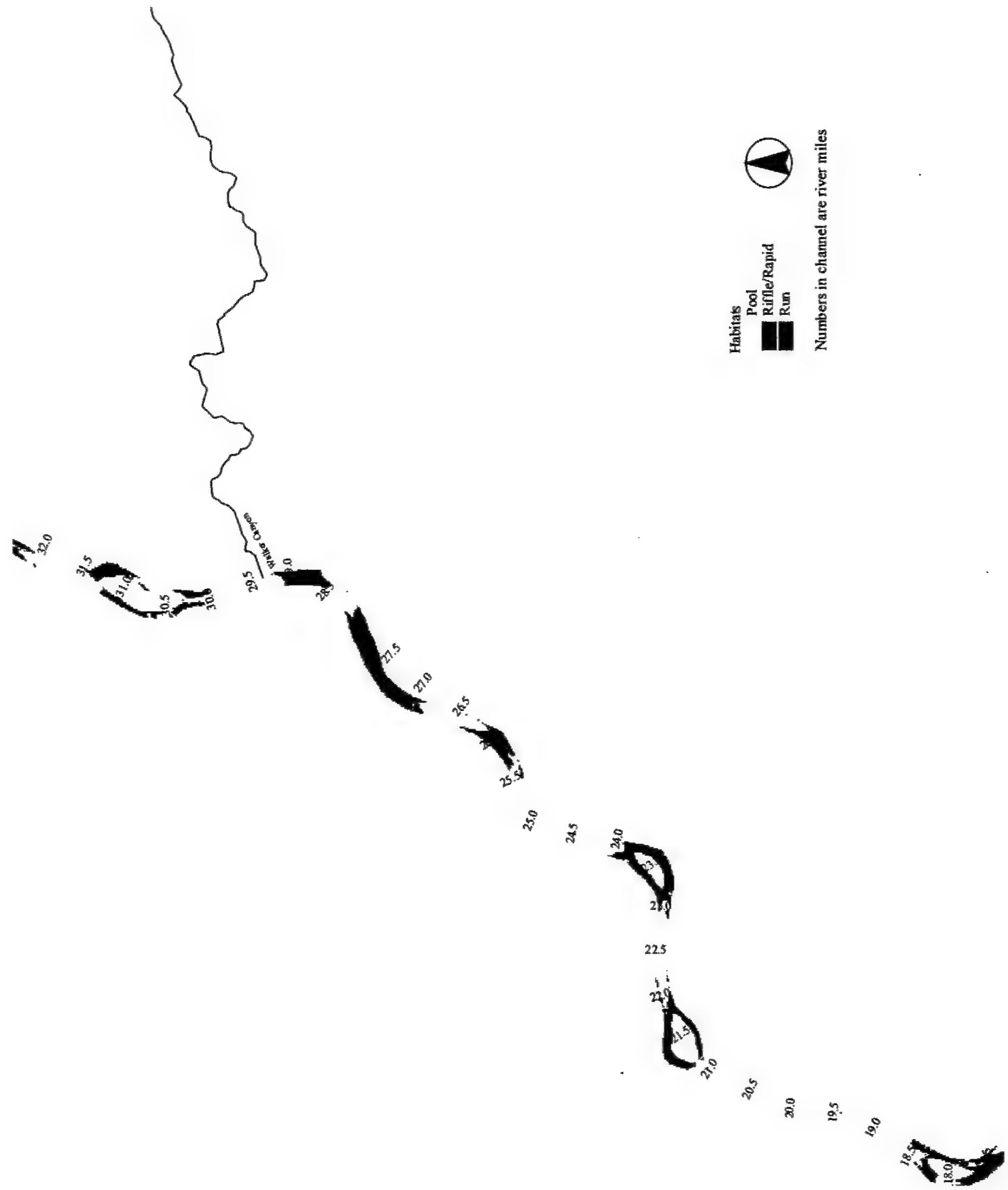


Figure 4-13. Pool, Run, and Riffle/Rapid Habitats

Table 4-5. Pool, Riffle/Rapid, Run Habitats of Lower Snake River Segments

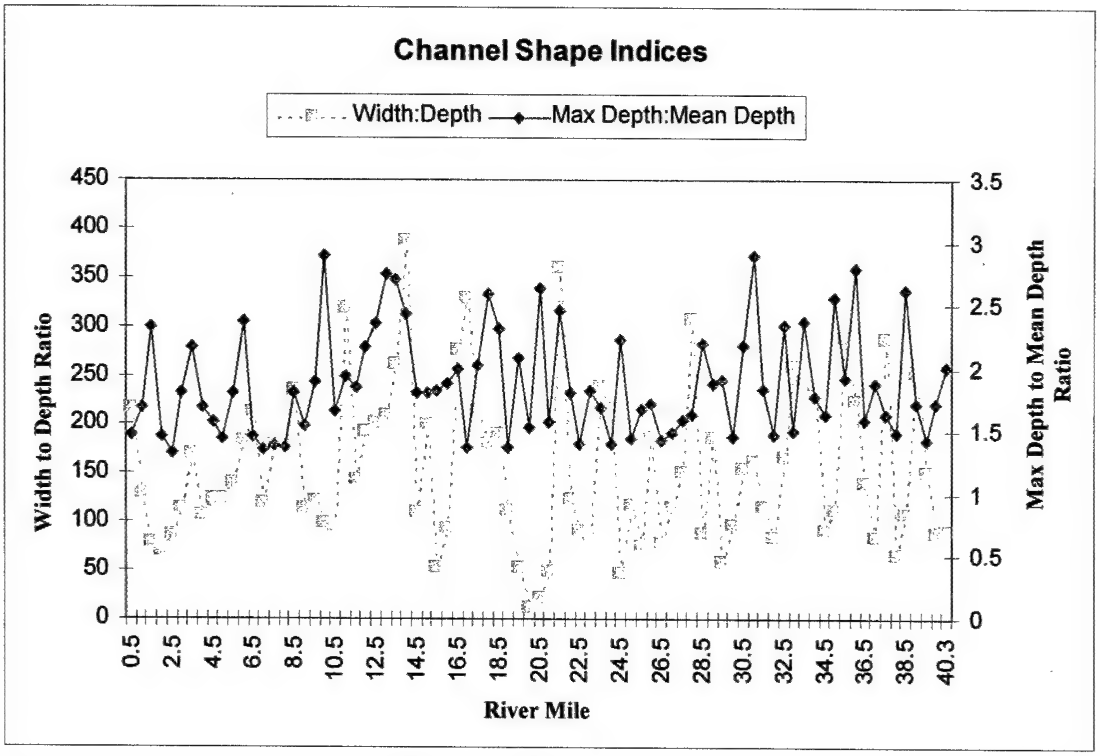
Segment	Habitat by Segments – Hectares (%)			
	Pool	Riffle/Rapid	Run	Total
Mouth to Ice Harbor	791.9 (97.7)	0.0 (0.0)	18.7 (2.3)	810.6 (100)
Ice Harbor to Lower Monumental	839.0 (57.5)	97.6 (6.7)	521.7 (35.8)	1458.3 (100)
Lower Monumental to Little Goose	694.8 (55.0)	72.1 (5.7)	495.8 (39.3)	1262.8 (100)
Little Goose to Lower Granite	970.2 (64.0)	72.9 (4.8)	471.9 (31.1)	1515.0 (100)
Upriver of Lower Granite	764.1 (70.5)	36.6 (3.4)	283.4 (26.1)	1084.1 (100)
Total	4060.0 (66.2)	279.2 (4.6)	1791.5 (29.2)	6130.7 (100)

The d_{max}/d parameter is an index of channel asymmetry. Channels with a d_{max}/d value approaching 1 are trapezoidal and regular in shape, while higher values indicate bedform diversity within a cross section. The cross sections in the pre-dam lower Snake River indicate variable d_{max}/d values, with lower values roughly corresponding to lower F values (Figure 4-14). The latter observation is indicative of narrow, deep river reaches that are trapezoidal in shape. A final parameter describing the variability in natural channels is the planform characteristic of top width. Top width was calculated at each cross section, based on the Q_{50} flow. Top widths in the study area were highly variable from cross section to cross section (Figure 4-15), indicating planform channel asymmetry.

4.4 Geomorphic Features and Salmon Production Areas

Redd density data is not available for fall chinook spawning in the lower Snake River. Such information has, however, been well documented for the remainder of the Snake River during most of the hydro development period (Battelle and USGS, 1999), and provided a means to evaluate the relationship of various geomorphic features and spawning density in the Snake River.

When we applied the geomorphic spawning habitat model to the lower Snake River (from the mouth upriver to Tenmile Rapids at rkm 238.5 (rm 148)—the upper limit of present day Lower Granite Dam reservoir), we estimated approximately 131 km (81 mi) of suitable spawning habitat may have been available during the pre-hydroelectric development period. This distance represents approximately 55 percent of the lower Snake River. In contrast, historical accounts of fall chinook spawning locations indicate that approximately 51 km (32 mi; 21 percent) of the lower Snake River was used as spawning habitat. Explaining the differences between these estimates is confounded by the quality and scarcity of historic spawning records for the lower Snake River. The historic records used were based on one account of estimated lineal river distance used for spawning, rather than repeated surveys, and may therefore be an underestimate. In a similar analysis for the remainder of the mainstem Snake and Columbia Rivers, the geomorphic model predicted 40 to 50 percent less suitable spawning habitat than what was actually documented to occur (Battelle and USGS, 1999).



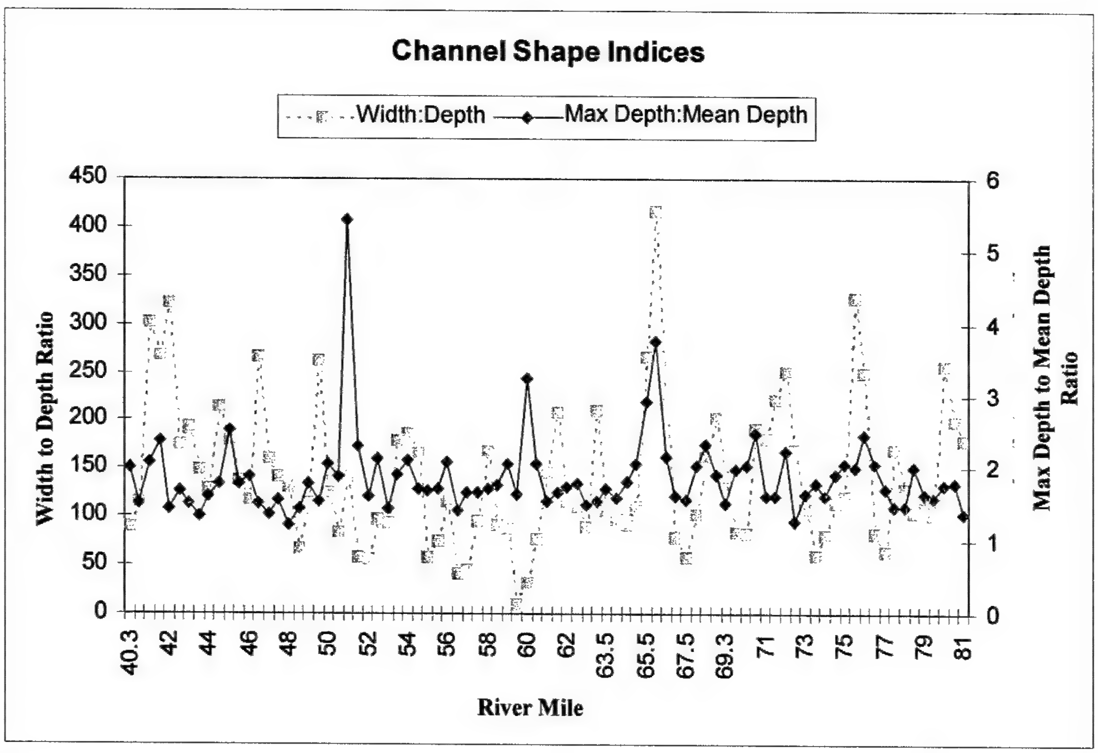
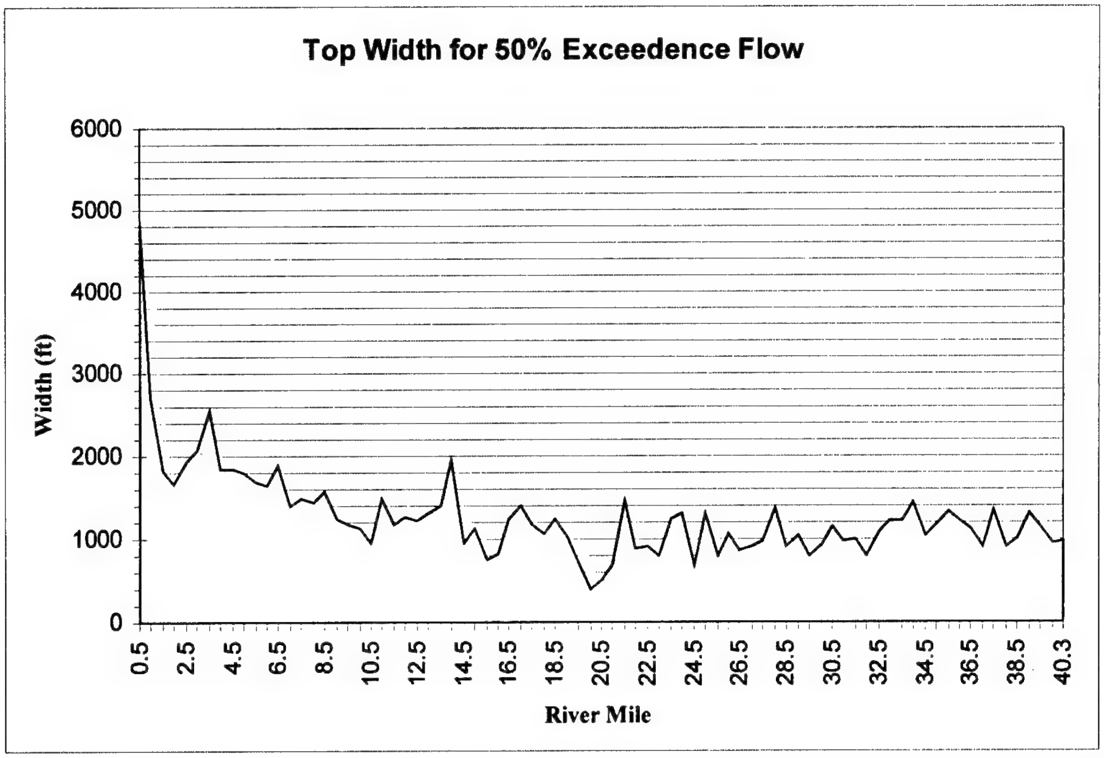


Figure 4-14. Channel Shape Indices at Each Cross Section for Q_{50} Flow



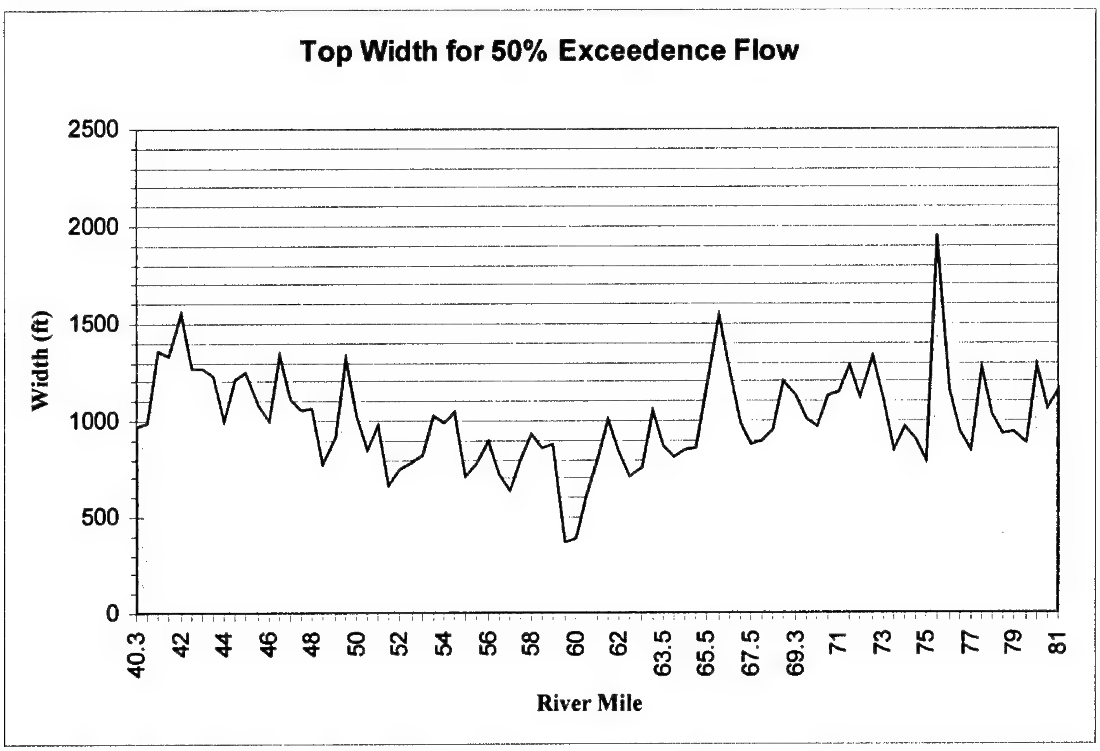


Figure 4-15. Top Width at Each Cross Section for Q_{50} Flow

Historical accounts of fall chinook spawning include the area from rkm 11 to 30 (rm 7 to 19; currently Ice Harbor Dam vicinity), from rkm 96-128 (rm 60 to 80; upstream of the Palouse River;), and near the confluence of the Clearwater River (Figure 4-16). The geomorphic model suggests that approximately 87 percent of the lineal river distance from Little Goose Dam upriver to Lower Granite Dam contains geomorphic characteristics conducive to fall chinook spawning (Table 4-6; Figure 4-16), or the largest portion of potentially suitable fall chinook spawning habitat on a dam-by-dam basis.

Table 4-6. Geomorphic Spawning Habitat Model Prediction for Lower Snake River Sections

Section	Section Length (km)	Modeled Spawning Suitability (km)	Percent of Section
Mouth to Ice Harbor	15.5	15.5	100.0
Ice Harbor to Lower Monumental	50.5	28.5	56.4
Lower Monumental to Little Goose	46.5	7.0	15.1
Little Goose to Lower Granite	59.5	52.0	87.4
Lower Granite to 10 mile Rapids	66.5	28.0	42.1
Lower Snake Total	238.5	131.0	54.9

The results of our geomorphic model were different than estimates of fall chinook spawning habitat based on traditional modeling characteristics of suitable depth, velocity, and substrate (USFWS, 1999). The USFWS (1999) recently estimated that the section from Lower Monument Dam to Little Goose Dam had the most potential spawning habitat under dam breaching (Table 4-7).

Table 4-7. Fall Chinook Spawning Habitat (Percent) Under Natural River Conditions Based on Modeled Depths, Velocities, and Substrates (USFWS, 1999)

	Location					
Suitability	Mouth to Ice Harbor	Ice Harbor to Lower Monumental	Lower Monumental to Little Goose	Little Goose to Lower Granite	Upriver of Lower Granite	Total
Not suitable	63.7	57.2	39.2	79.9	92.3	66.6
Suitable	32.9	31.0	40.7	12.2	2.8	23.5
Unknown	3.5	11.8	20.2	7.9	4.9	10.3

The geomorphic model helps refine where fall chinook salmon would spawn, however estimating surface area of a section of river used for spawning (microhabitat scale) requires the inclusion of finer-scale geomorphic variables. This scaling discrepancy is evident at the Hanford Reach of the Columbia River, where we have an extensive dataset of fine-scale fall chinook spawning locations and density. The geomorphic model predicts 66.5 km (41 mi; 67 percent) of suitable spawning habitat in the Hanford Reach. The surface area actually used for redds (based on aerial surveys [Dauble and Watson, 1997] and underwater video) is only approximately 5 percent.

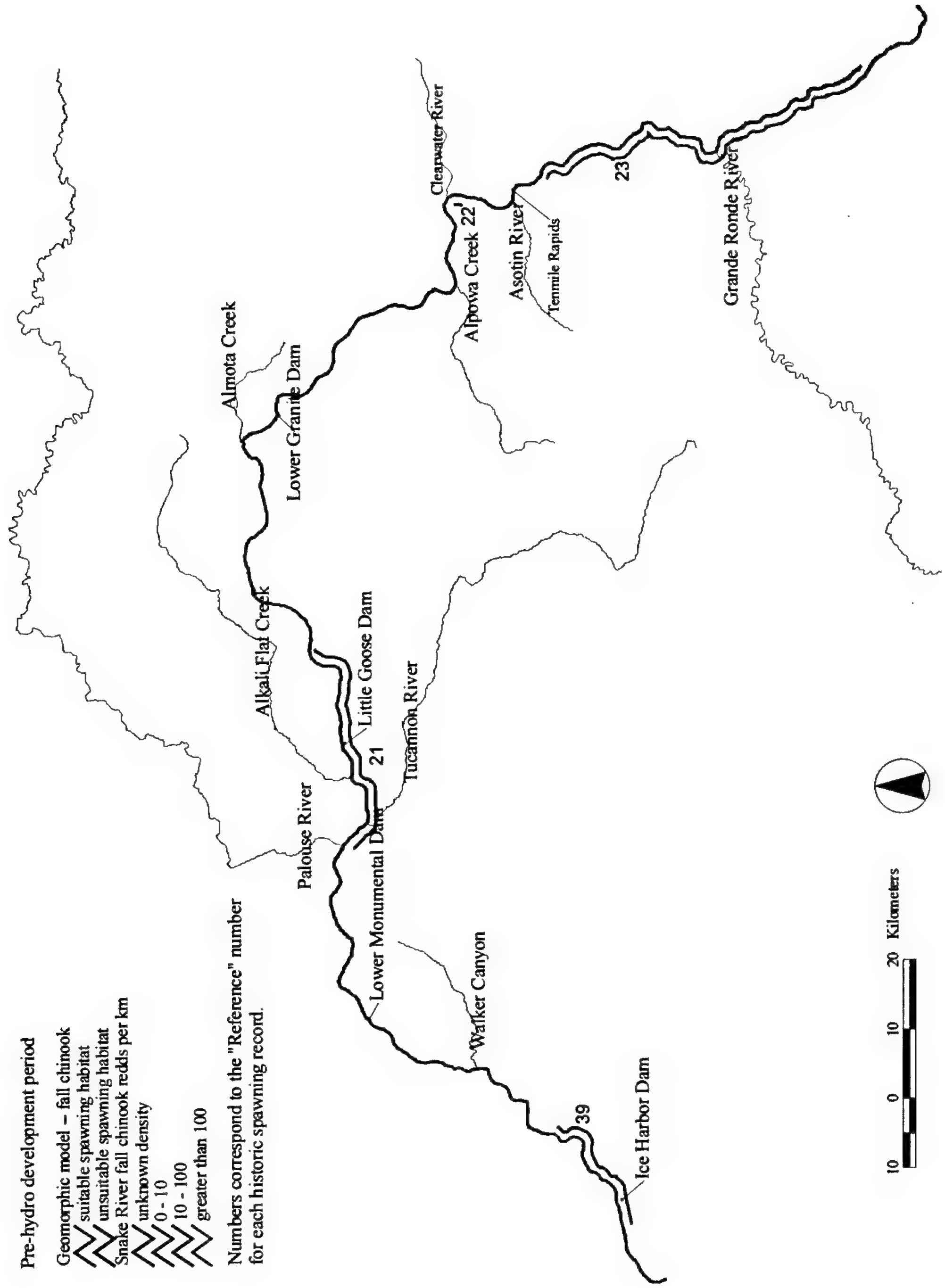


Figure 4-16. Geomorphic Spawning Habitat Model and Pre-hydro Development Period Fall Chinook Spawning Locations. Reference Numbers Correspond to Historical Records Provided in Appendix A of Battelle and USGS (2000).

4.5 Flow Regime and Sediment Transport

Historical discharge records provided a means of comparing pre-major storage flow regimes with post-major storage flow regimes to determine if the latter has a geomorphic competency similar to the former. The annual maximum discharge, pre- and post-major storage, has not changed much (Figure 4-17). The mean of pre-major storage period annual maximum discharge is 5,326 cms (188,087 cfs), while the mean for the post-major storage period is 4,793 cms (169,257 cfs; Table 4-8).

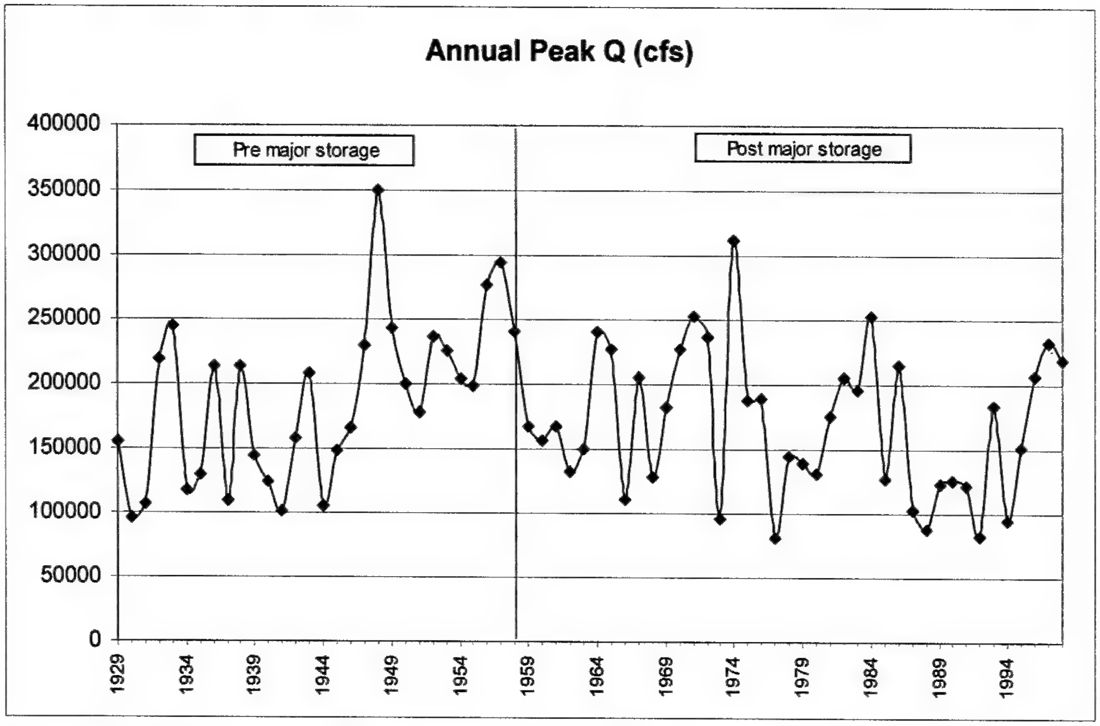


Figure 4-17. Lower Snake River Annual Peak Discharge, 1929 to 1998

Table 4-8. Lower Snake River Change in Annual Maximum Discharge for Pre- and Post-major Storage Periods (Units Are in cms [cfs])

	Pre-major Storage	Post-major Storage	Change	Post Percent of Pre-major Storage
Mean	5,326 (188,087)	4,793 (169,257)	533 (18,830)	90
Range	7,204 (254,400)	6,556 (231,539)	647 (22,861)	91
Minimum	2,707 (95,600)	2,290 (80,882)	417 (14,718)	85
Maximum	9,911 (350,000)	8,847 (312,421)	1,064 (37,579)	89

The geomorphic competency (erosional and depositional processes affecting morphological change) of a river is often determined by the bankfull flow (Hey, 1997). The return period of bankfull flow for gravel-bed rivers is commonly determined as the 1.0- to 2.0-year flood, based on the annual maximum series (Leopold et al., 1964; Williams, 1978). Because this method excludes lesser flood events above bed material transport thresholds, return periods based on partial duration series with a

threshold discharge set at the initiation of bed material movement have been used as an alternative (Carling, 1988; Hey and Heritage, 1988; Hey, 1997). This method yields a return period once every 0.9 years for bankfull flow in UK gravel-bed rivers (Hey and Heritage, 1988; Hey, 1997). To compare pre- and post-major storage geomorphic competency, we set the threshold value at the pre-major storage 1.0-year flood, based on the annual maximum series. During the pre-major storage period this threshold discharge was equaled or exceeded 13 percent of the time. This percentage increased to 14 percent during the post-major storage period, suggesting no considerable difference in the geomorphic competency between the two periods. On an annual basis, the number of days the threshold discharge was equaled or exceeded ranged from 1 to 100 and 0 to 121 during the pre- and post-major storage periods, respectively.

The frequency of occurrence of the threshold discharge during any given year is particularly important in evaluating the time period expected for remobilization of the lower Snake River channelbed surface. The flow required for initiation of bedload transport can be much higher than typical criteria for rivers with a prolonged period of no sediment transport, and containing infiltrated cohesive fine sediments that create a powerful cementation effect (Reid et al., 1997); conditions analogous to those in the impounded lower Snake River. During the first flood event following such conditions bedload transport may be minimal, but will increase during subsequent flood events occurring with greater frequency (Reid et al., 1985). Therefore, the time period required for critical transport conditions in the lower Snake River will depend to some extent on the number of days the threshold discharge is equaled or exceeded in each year following dam breaching. This frequency is subject to the natural variability of water year types, ranging from extremely wet to extremely dry.

The geomorphic competency of the lower Snake River under the dam breaching is also reflected in estimates of fine sediment transport. It was estimated that the majority of fine sediments accumulated in Lower Granite Reservoir would be eroded and transported within 5 years of the removal of Lower Granite Dam (Figure 4-18; Hanrahan et al., 1998). These estimates are in agreement with observations made during the 1992 drawdown test of Lower Granite Dam reservoir (Corps, 1993), and with modeled estimates of sediment mobility in the lower Snake River as a whole (Richmond et al., 1999).

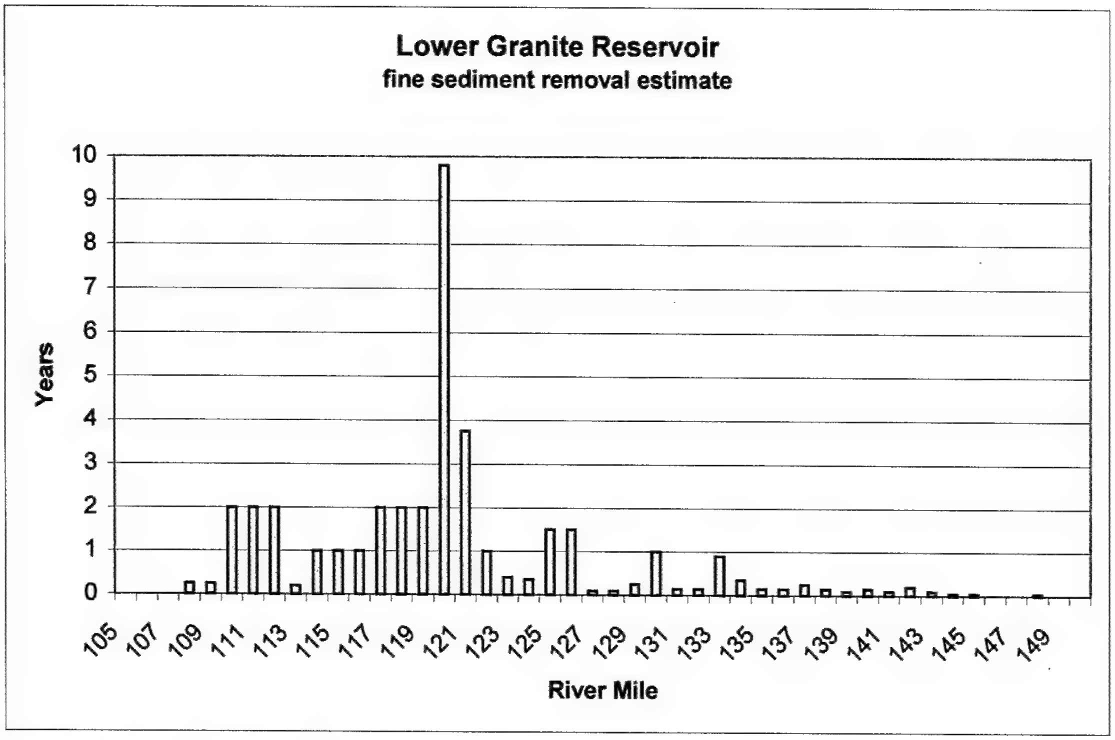


Figure 4-18. Estimated Time to Remove Fine Sediments From Lower Granite Reservoir Under Dam Breaching

This page is intentionally left blank.

5. Conclusions and Recommendations

Prior to impoundment, the lower Snake River exhibited heterogeneous characteristics ranging from those typical of alluvial reaches to those typical of bedrock-confined reaches in large rivers. In general, the pre-dam channel was a morphologically diverse, coarse-bedded, stable river possessing a meandering thalweg and classic pool-riffle longitudinal bedform profile.

The geomorphic model of fall chinook spawning habitat suggests that several alluvial and partially-alluvial reaches may be particularly important restoration areas. Two such areas within the lower Snake River are from the mouth upriver to approximately RKM 31 (RM 19), and near the confluence with the Clearwater River from RKM 215 to 229 (RM 134 to 142). One large contiguous section potentially suitable for fall chinook spawning extends from approximately RKM 106 to 193 (RM 66 to 120), which includes much of the Little Goose Reservoir.

Analysis of historic and contemporary discharge records indicates that regulated flow regimes after dam breaching would be competent enough to maintain channel characteristics and riverine processes (e.g., channelbed mobilization). The time required before the realization of these characteristics and processes depends on many interrelated factors, including an initial 5-year to 10-year period of erosion and transport of fine sediments accumulated in the reservoirs since dam construction. After the bulk of those fine sediments are removed, the competency of the regulated flow regime (particularly the annual maximum discharge) will be sufficient to mobilize the channelbed surface. The time required for the initiation of such processes depends on the annual flow regimes during the period following dam breaching, particularly the frequency and duration of annual maximum discharge equaling or exceeding the pre-major storage period 1-year flood of 2,707 cms (95,600 cfs).

The results of this study address several primary issues concerning breaching of the four lower Snake River dams, including: 1) understanding the physical characteristics of the pre-dam river; 2) determining the extent and location of pre-dam fall chinook spawning, as well as potential locations for post-drawdown fall chinook spawning; and 3) determining if the post-breaching flow regime is competent to maintain important geomorphic processes. The results provide a starting point for continued analyses of post-breaching fluvial geomorphology at a much finer scale.

The proposed breaching of the four lower Snake River dams can be viewed as an attempt to restore riverine conditions to what is currently a series of impounded reservoirs. The ultimate goal of this effort is the restoration of anadromous Snake River salmonid populations. The restoration of these populations arguably necessitates the recovery of a healthy river ecosystem (Stanford et al., 1996), not simply the restoration of habitat (e.g., suitable spawning depth, velocity, and substrate) for one or two species. The spatial and successional patterns of biological communities in river ecosystems are controlled by the abiotic attributes describing the hydrology, geomorphology, and water quality (Lorenz et al., 1997). Some of the essential abiotic attributes applying generally to alluvial and partially-alluvial rivers are listed in Table 5-1.

Table 5-1. Alluvial River Attributes [1/]

Attribute	Description	Ecological Significance
Spatially-complex channel morphology	Alternate bar morphology, m side channels and backwater areas, asymmetrical cross sections, etc.	Provides diverse salmonid habitat availability for all life stages over wide-ranging flows
		Supports diverse and productive biological communities
		Develops and maintains diverse riparian plant communities in all stages of succesional development
Natural variability in flows and water quality	Natural periodicity, duration, and seasonal timing of baseflows, spring/summer runoff, and winter floods	Inundation of bar features during dispersion of riparian plant seeds discourages germination on bars
		Variable water depths and velocities over spawning gravels during salmonid spawning spatially distributes redds
		Inundation of alternate bar margins, including backwater scour channels, creates shallow slackwater areas between late-winter and snowmelt periods for early life stages of salmonids and amphibians
		Provides favorable ranges of baseflows for maintaining high quality juvenile salmonid rearing and macroinvertebrate habitat within an alternate bar morphology
		Provides late-spring outmigrant stimulus flows
		In general, optimizes salmonid physical habitat availability for all seasons
		In general, restores groundwater/surface water dynamics and maintains hyporheic habitats
		In general, restores floodplain/riparian processes associated with a snowmelt hydrograph
Frequently mobilized channelbed surface	Coarse sediment surfaces are mobilized by the bankfull discharge, which on average occurs every 1 to 2 years	Reduced substrate embeddedness in riffle/run habitats increases survival of eggs and emerging alevins
		Scouring and reduced sand storage in pools creates greater pool depths/volumes for adult fish cover and holding
		Provides turnover of spawning gravel deposits and mobilizes those deposits several layers deep
		Provides greater substrate complexity in riffle and run habitats for improved macroinvertebrate production
		Decreases riparian encroachment by scouring seedlings on bars
		In general, increases micro-habitat complexity

Table 5-1. Alluvial River Attributes [1/], continued

Periodic channelbed scour and fill	Channelbed and bars are scoured deeper than the coarse surface layer by floods exceeding 3- to 5-year annual maximum flood recurrences	Scouring below bed surface layer rejuvenates spawning gravel deposits Facilitates bar evolution (e.g., alternate, medial), improving channel-wide spawning and rearing habitat complexity Maintains and/or improves pool depths for adult salmonid cover and holding Increases diversity of surface particle size distributions Removes vegetation from bar surfaces, discouraging riparian plant encroachment and bank accretion Deposits fine sediment onto upper alternate bar and floodplain surfaces, thereby reestablishing dynamic riparian stands of vegetation in various stages of succession
Periodic channel migration	"Typical" bank erosion rates, floodplain deposition every 3 to 5 years, and channel avulsions every 10 years on average	Diverse age class structure of woody riparian vegetation, producing and maintaining early- successional riparian communities Increase in woody riparian overstory and understory species diversity Increased habitat quality and quantity for native vertebrate species dependent on early successional riparian stands High flow refuge and summer thermal refuge for amphibians and juvenile fish provided in rejuvenated scour channels Salmonid habitat complexity is improved through creation of sloughs and side channels Increasing micro-habitat complexity from input of large woody debris caused by bank erosion
Balanced fine and coarse sediment budgets	Fine and coarse sediments are exported at rates approximately equal to sediment inputs. Channel morphology is maintained in "dynamic quasi-equilibrium"	Reduced fine sediment storage and maintained coarse sediment storage improves spawning habitat quality without reducing quantity Mobilization of coarse sediments and preventing mainstem accumulation of fine sediments increases pool depths for adult salmonid cover and holding, and improves physical complexity through bar evolution Reduced fine sediment storage in banks lessens bank accretion, thereby allowing continual evolution of channel morphology Discouraging bed elevation aggradation at tributary deltas maintains salmonid migration corridors
Functional floodplain	Areas where fine sediments can be removed from the inner channel and deposited	Through scour and deposition, floodplain construction rates roughly equal floodplain loss as channel migrates Provides sufficient channel confinement, such that hydraulic processes can be maintained Increases hydraulic roughness, and allows greater flow storage during high magnitude floods Maintains riparian vegetation dynamics, such as varying stages of successional development

Table 5-1. Alluvial River Attributes [1/], continued

Infrequent channel resetting floods	Those that exceed the 10- to 20-year annual maximum flood recurrence	Salmonid habitat complexity and quantity is improved through deep scour of channel features, significant channel migration and avulsion (creating sloughs and side channels), and alternate bar scour and redeposition Maintain riparian vegetation dynamics, such as varying stages of successional development Disturbs bar surfaces close to channel center to discourage riparian encroachment Provide habitat for riparian-dependent amphibian, avian, and mammalian species Improves bedload routing by minimizing impedance of bedload transport past tributary deltas
Self-sustaining diverse riparian plant communities	Successional stages and species composition similar to other regional unregulated river corridors	Increase in species diversity, and age class diversity Increase in riparian habitat complexity Allows rehabilitation of evolving channel features (e.g., alternate bars, sloughs) Vigorous woody riparian corridor moderates physical effects of extreme floods Increases availability of habitat for riparian-dependent amphibian, avian, and mammalian species Moderates water temperatures at the micro- habitat scale
Interstitial flow pathways and ground water/surface water interactions	Hyporheic habitats form because of interstitial pathways between surface water and groundwater. Hydrology of floodplains, terraces, sloughs, and adjacent wetlands fluctuate in response to natural hydrograph of river corridor	Maintains off-channel habitats, including overflow channels, oxbow channels, and floodplain wetlands Promotes diversity of habitat types within entire river corridor Farms and maintains hyporheic habitats, which diversify salmonid spawning and rearing habitat (e.g., increased interstitial flow through redds, temperature refugia, water quality control, etc.)

1/ Compiled from several sources, primarily the Trinity River Restoration Program (Hoopa Valley Tribe, 1997).

The post-impoundment functioning of the lower Snake River could be regarded as more ecologically sustainable, as the functional and structural characteristics come closer to the alluvial river attributes described in Table 5-1. The rate and pathways for recovering these attributes in the lower Snake River depend on many interrelated factors, one of which is the physical template set by the river prior to impoundment (the pre-dam channel morphology described in this study). Other factors, yet to be addressed or resolved, governing the recovery of lower Snake River physical processes and characteristics include:

- Post-impoundment management of the lower Snake River flow regime (magnitude, timing, duration, and frequency of base flows, bankfull flows, riparian flows, and floodplain flows)

- Quantitative sediment budgets for the Snake River and its tributaries
- Quantitative assessments of existing substrate composition in the lower Snake River
- Quantitative assessments (e.g., spatial extent, composition, effects) of existing riprap along banks
- Quantitative assessments (e.g., spatial extent, composition, effects) of proposed shoreline protection, velocity control structures (e.g., riprap, levees) and other channel alterations following dam breaching
- Quantitative assessments (e.g., spatial extent, composition, effects) of river channel alterations occurring between 1934 and completion of the first lower Snake River dam (1961), and from 1961 to present-day (e.g., channel/reservoir maintenance, dredging, in-channel disposal)

- Quantitative assessments of the hydraulic and geomorphic effects upriver, at the dam, and downriver resulting from the dam structures remaining in place (e.g., navigation lock, spillway, powerhouse) after dam breaching

These and other factors determine the rate and means by which the lower Snake River will evolve from its present condition to that described by the pre-dam channel morphology. A prediction of the precise style and rate of this channel adjustment is precluded by the nonexistence of quantitative process-response models of channel adjustment (Richards, 1982; Hooke, 1997). The interdependence of the nine or more variables defining and controlling stable channel geometry (Hey, 1997), which respond differently to changes in sediment quantity and composition and flow regime, confounds even qualitative predictions of channel adjustment (Hooke, 1997). Moreover, these changes in sediment yield and flow regime are naturally altered simultaneously but to different and variable degrees, often with secondary responses (Richards, 1982). The magnitude and direction of channel change in response to changes in sediment yield and flow regime can be addressed qualitatively through relationships originally proposed by Schumm (1969). The nature of the channel response for any given segment of the lower Snake River depends on the inherent instability, the freedom to adjust (vertically and laterally), and the sensitivity of different environments and reaches to change (Hooke, 1997). The classification of the lower Snake River into distinct geomorphic units—the template controlling stability and sensitivity—provides a framework for developing hypotheses of possible channel responses.

This page is intentionally left blank.

Part 2

Two-dimensional Analysis of Hydraulic Conditions and Sediment Mobility in the Lower Snake River for Impounded and Unimpounded River Conditions

6. Summary

The lower Snake River hydrograph is affected by water and land management practices throughout the watershed, and controlled by upstream dam releases, consequently, it is certain that the river channel will not be restored to its pristine pre-development condition by removing the four lower Snake River dams. Exactly how the resultant channel bed would differ from the original channel is uncertain, although this study does provide a comparative analysis of impounded and unimpounded river conditions.

The objective of the study was to compare hydraulics and sediment mobility in the lower Snake River for current and unimpounded river conditions using a mathematical model of the river and water quality model. The analysis used three steady flow conditions corresponding to the discharged exceeded 10, 50, and 80 percent of the time (based on historical flows).

The results of the hydraulic simulations showed that, for the 50 percent exceedance flow (31,710 cfs), the unimpounded river conditions are characterized by a wider range of depth-average velocities. For impounded conditions, the majority of river area had velocities less than 2 feet per second. In comparison, the unimpounded river condition shows that most of the velocities are in the range of 1 to 8 feet per second. The unimpounded conditions case also shows that velocities will be more evenly distributed over that range.

Based on critical velocity criteria, simulations for the 50 percent exceedance flow for impounded conditions showed that mainly sediments finer than a medium sand (0.25 mm diameter) would be mobilized or remain in transport. In the unimpounded river case, the same flow would mobilize medium (16 mm) to coarse gravel (64 mm) or finer material over most of the river channel. Thus, for typical flow conditions, most of the fine sediments that have been deposited in the lower Snake River reservoirs will be remobilized and transported downstream. The dominance of coarse material is consistent with current observations of substrate composition in the areas immediately downstream of the dams.

Recent research on gravel-bedded streams indicates that the bed shear stress may have to be three times higher to initiate movement in a substrate composed of coarse materials interlaced with fine sediments, as compared to the uniform bed criteria. The potential decreased mobility of the coarse materials (larger than fine gravel) was examined using a velocity criteria 1.5 times higher than the uniform criteria. Under those conditions, 10 percent exceedance flows (111,500 cfs) may be required to mobilize the same area of coarse materials, as was the case using the uniform criteria at the 50 percent (31,170 cfs) exceedance flow.

This page is intentionally left blank.

7. Introduction

The goals of this analysis are to provide an improved understanding of the differences in hydraulic regimes between the current (impounded) and "natural" (unimpounded) conditions, as well as to estimate sediment mobility for each condition. This is accomplished using a two-dimensional (2D), depth-averaged, hydrodynamic model to simulate the velocity distribution in the river. Estimates of the size of sediment that can be mobilized are then developed using the simulated velocities, along with sediment movement criteria based on critical velocity or shear stress.

7.1 Geographic Scope

In this work, the term "lower Snake River" refers to the area of the Snake River where the model was applied. This analysis area goes from the mouth of the Snake River (river mile 0), at the confluence with the Columbia River, to Snake River mile 168, near its confluence with the Grande Ronde River. A small reach of the Clearwater River (about 1 mile) is also included. This geographic scope is shown in Figure 7-1.

7.2 Key Assumptions and Limitations

The analysis presented in this report contains several assumptions and limitations:

- The long-term (after dam breaching) future channel course and bathymetry is represented by historical pre-dam bathymetric surveys;
- Sediment mobility or transport potential is described by critical velocities;
- Steady-state flows are adequate to perform a comparative analysis; and
- The evolution of the channel bed is not simulated.

Assuming that the long-term channel configuration is represented by pre-dam bathymetry is reasonable considering that the lower Snake River was primarily a non-alluvial system characterized by armored cobble/gravel bed materials and areas of bedrock. If the dams are breached, the river will cut through existing fine material that has been deposited, and the floodplain will widen to its former limits with successive high flows as remaining fine sediments are eroded. At small scales, there will obviously be differences between the channel that existed prior to dam closure and that which would form 5 to 10 years after dam breaching. For the present purpose of characterizing the differences in hydraulic conditions at a large scale, performing the analysis based on historical bathymetry is adequate.

The primary reason for not simulating the evolution of the channel bed, beginning from dam breaching to some future stable state, is the lack of available data, along with the uncertainty of sediment transport modeling in general. Such a modeling effort will require field surveys to characterize the existing channel bed elevation, estimated depth of sediment, bed sediment grain size distribution, and incoming sediment loads (some older data are available in Jones and Seitz 1980). Some of this data exists for Lower Granite Lake (Figure 7-2) but, even there, it is sparse and biased to nearshore locations or towards finer sediment sizes. In addition to inriver sediment transport processes, the erosion and overland transport of material along the exposed shore that will appear when the water level drops should be accounted for in any modeling effort. The rate and extent of revegetation should also be considered. Without additional data, bed evolution simulation would, at best, be highly speculative at the present time.

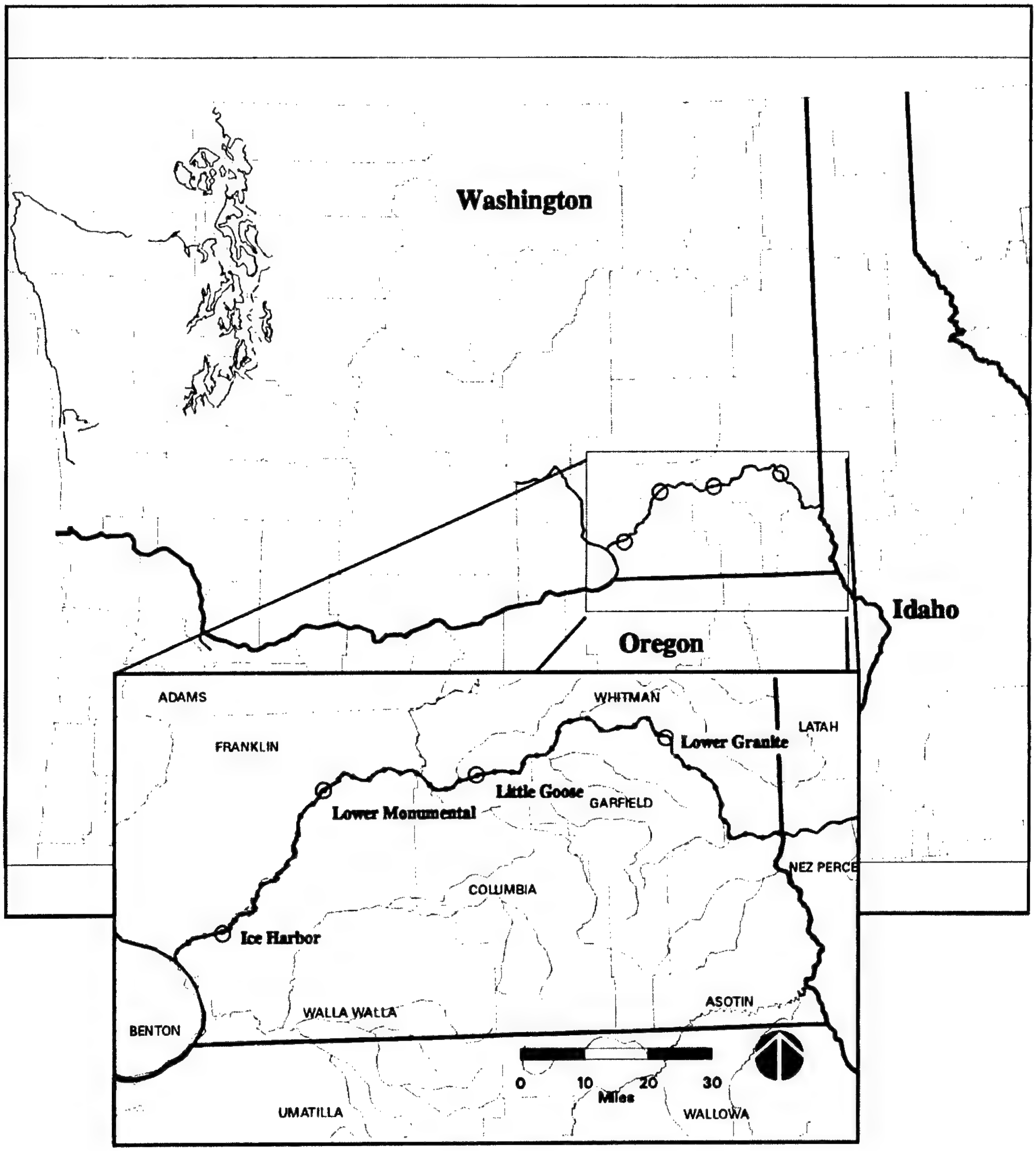


Figure 7-1. Reach of the Lower Snake River Where the 2D Model Was Applied in This Analysis

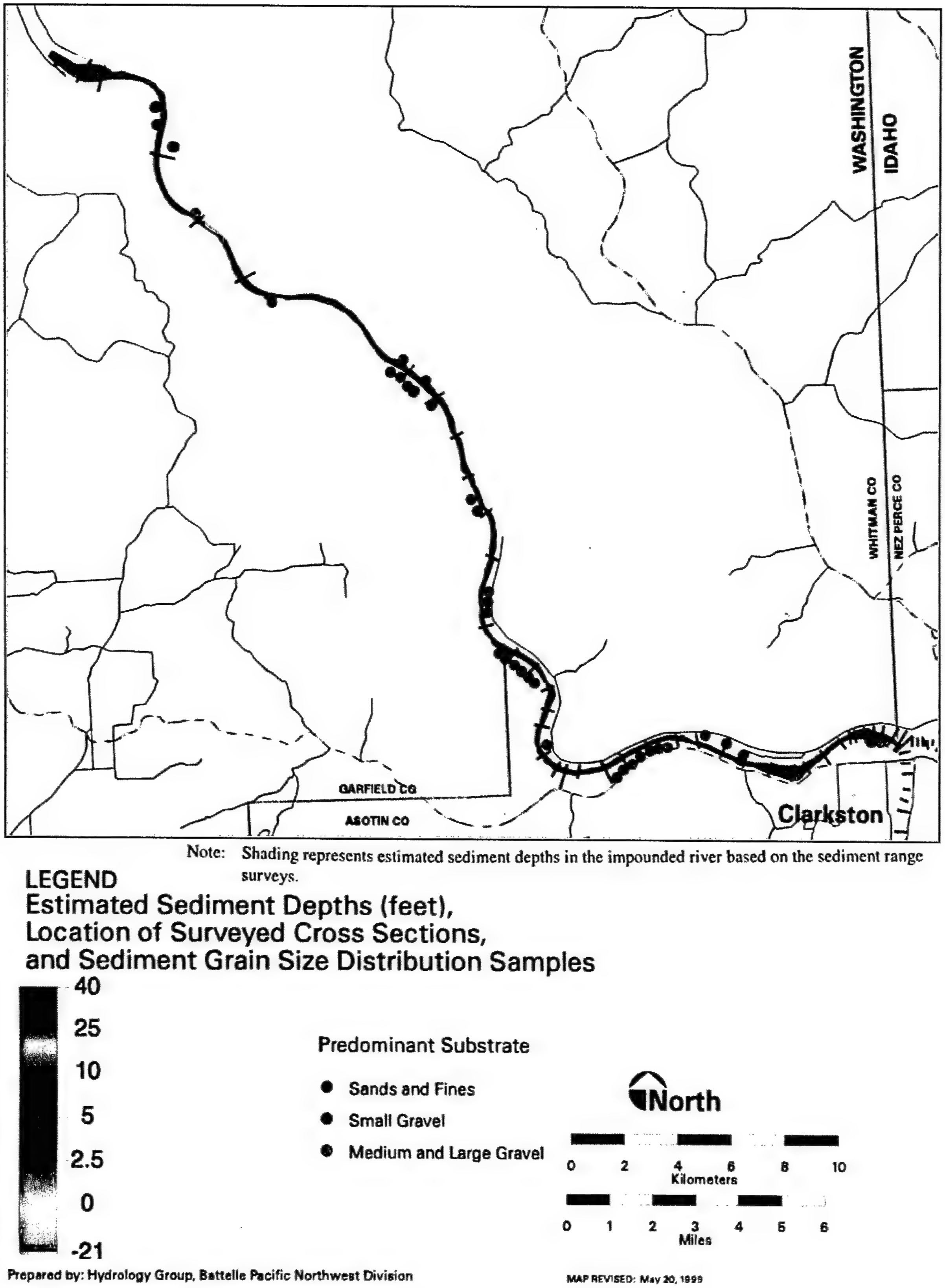


Figure 7-2. Location of Surveyed Sediment Ranges and Grain Size Distribution Samples

This page is intentionally left blank.

8. Methods

The analysis of hydraulic conditions for both impounded and unimpounded river conditions uses a two-dimensional (2D), depth-averaged, hydrodynamic model. This section presents the essential aspects of the numerical model, bathymetric data, boundary conditions, and parameters.

8.1 2D Model

The 2D model used in this analysis is the Modular Aquatic Simulation System 2D (MASS2), developed for the Dissolved Gas Abatement Study (DGAS) for the Corps (Richmond at al., 1998). This model was selected because it has been configured and applied to the lower Snake River analysis area for impounded conditions. Applying the model for natural river conditions only required setting up new computational grids, as described below.

The MASS2 model simulates unsteady hydrodynamics (flow) and transport for 2D depth-averaged conditions. The MASS2 is a finite-volume code that uses a structured multi-block, curvilinear grid system. The 2D model numerically solves the governing equations of mass and momentum conservation to yield values of the water surface elevations, velocity, temperature, and total dissolved gas (not used in the Feasibility Study). These values are produced at each grid cell for every time step in the simulation. Output results can be captured as time-series data, a specific grid cell, or as spatial snapshots over the entire simulation domain for a certain time. The spatial results can be imported into GIS software for further analysis and map production. A complete description of the model and its application to the lower Columbia and Snake Rivers is provided by Richmond et al. (1998).

8.2 River Bathymetry and Computational Grids

A 2D depth-averaged model, such as MASS2, represents the river as a system of cells in a computational grid. This grid is constructed using geographic information describing the river shoreline and bathymetry (bottom elevation). The specific procedures for generating the computational grids for MASS2 are described in the DGAS summary report (Richmond et al., 1998).

Grids for the impounded conditions were the same as those used in the DGAS study. The bathymetry data used in those grids are based on present-day measurements, which are adequate for 2D modeling for full-pool conditions. These bathymetric data are too coarse (unless subjected to an excessive degree of smoothing) for 2D modeling, except for Lower Granite Lake and areas within about 1 mile of the downstream dams. An example of a grid for impounded conditions is shown in Figure 8-1.

Bathymetry and shoreline data for the natural river grids are based on electronically-digitized versions of the so-called 1934 linens (Corps, 1934). This data has sufficient resolution to use in a 2D model. These data are also consistent with the objective of simulating representative hydraulic conditions that would be present several years after a return to natural river conditions. Two grids were developed using the 1934 data: one for use in the 10 percent exceedance case and one for the 50 percent and 80 percent exceedance cases. Figure 8-2 is an example of the grid for the 50 percent exceedance case.

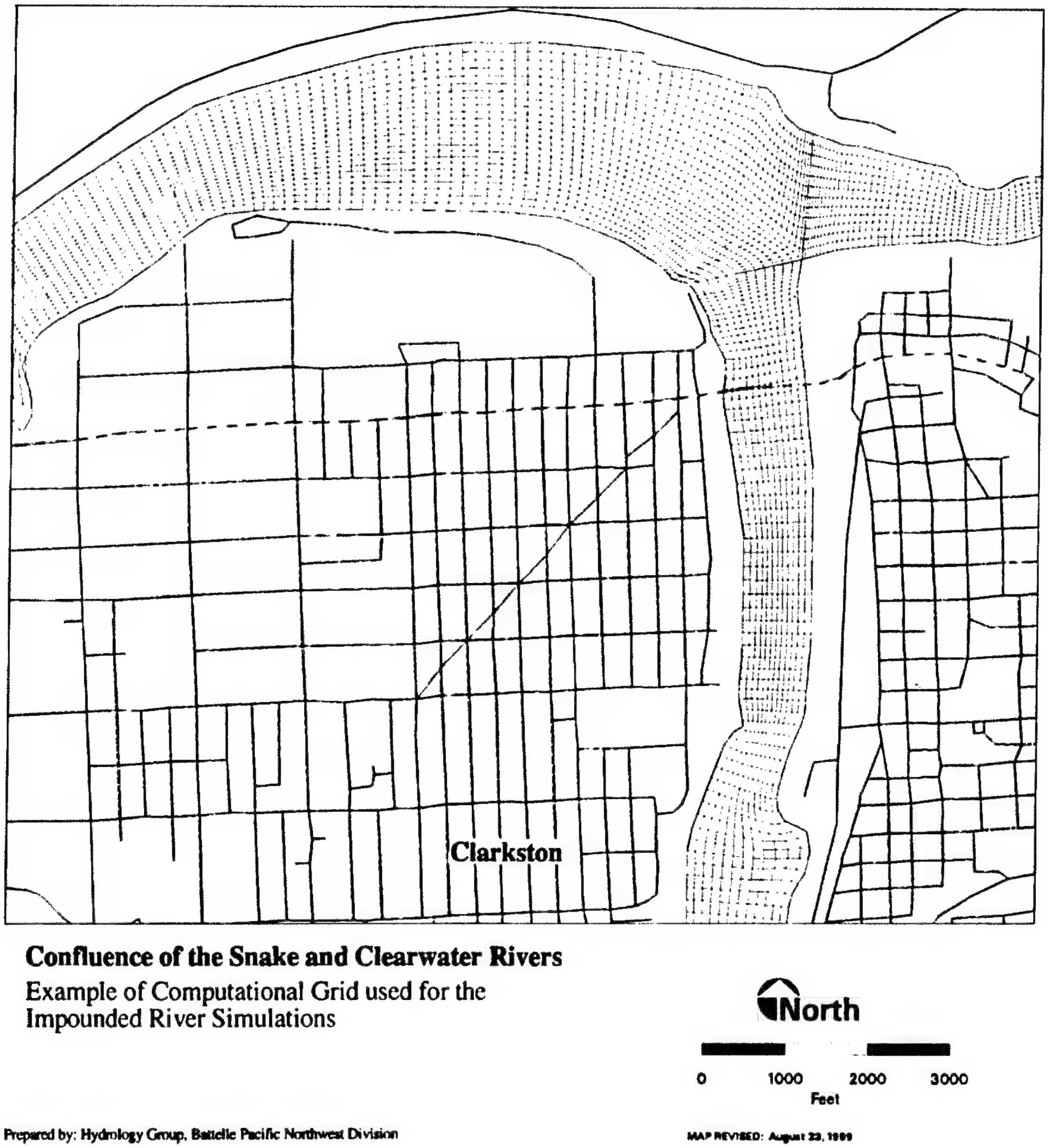


Figure 8-1. Example of the Computational Grid Used in the Full-pool, Impounded Conditions Simulations

8.3 Model Boundary Conditions and Parameters

The model was run for three steady-flow conditions corresponding to the 10 percent, 50 percent, and 80 percent exceedance flows for impounded conditions and natural river conditions. These exceedance flows were calculated in Hanrahan et al. (1998). The exceedance or flow duration is shown in Figure 8-3, and selected values are given in Table 8-1. The total flow at Lower Granite Dam was split between the Snake and Clearwater Rivers to assign model inflows, using fractions of 2/3 and 1/3, respectively.

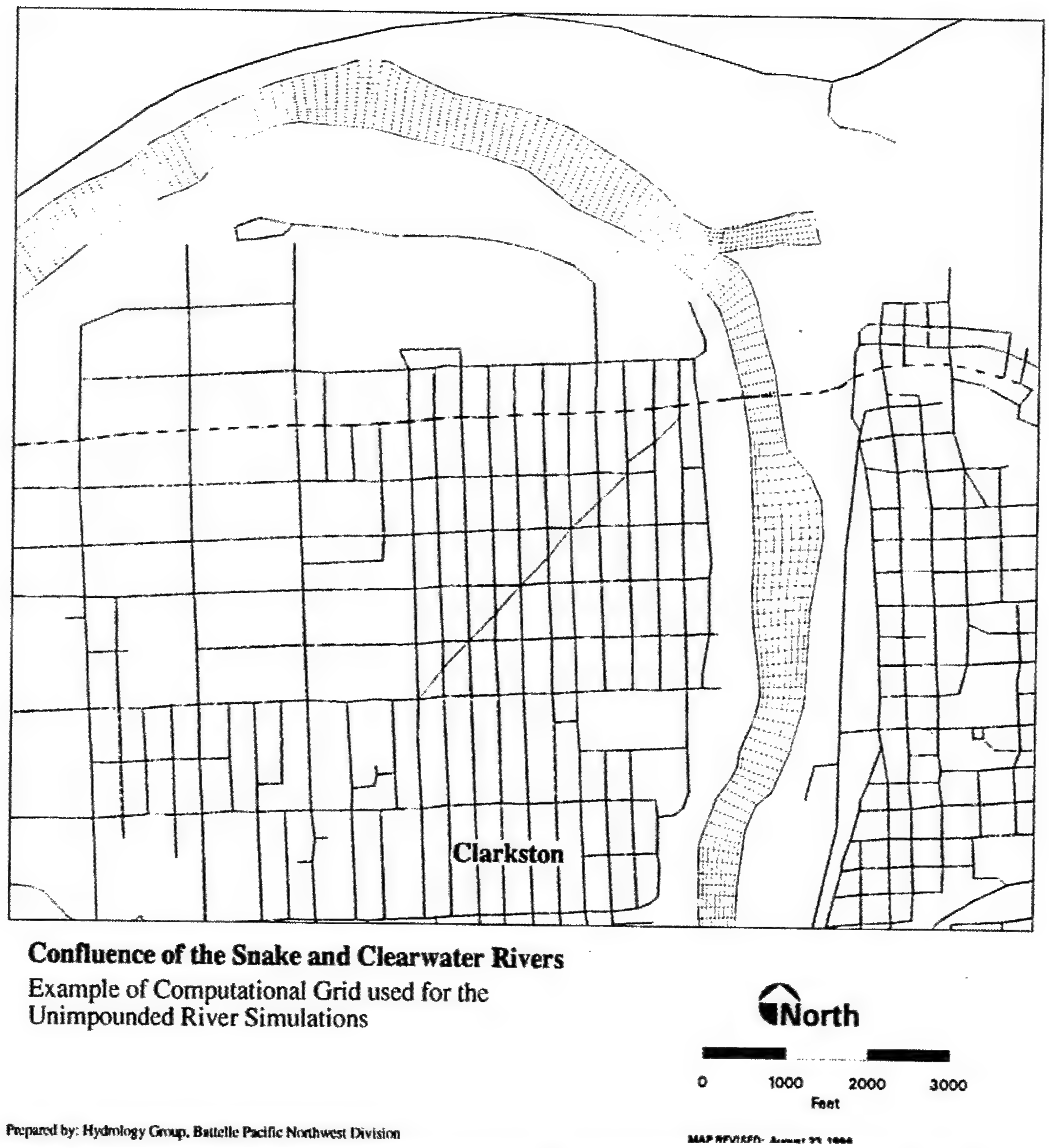


Figure 8-2. Example of the Computational Grid Used in the Unimpounded River Conditions Simulations

Inflows from other tributary streams (i.e., the Palouse and Tucannon) were not included in these simulations, because they are less than 2 percent of the Snake River flow at Lower Granite Dam.

Simulations for impounded conditions used steady-state forebay elevations corresponding to the normal operating pool elevation for each reservoir. For both the impounded and natural river simulations, a water surface elevation was specified at the confluence of the Snake and Columbia rivers. These various elevation boundary conditions are summarized in Table 8-2.

Manning roughness coefficients of 0.024 and 0.028 were used in the impounded and unimpounded river condition simulations, respectively.

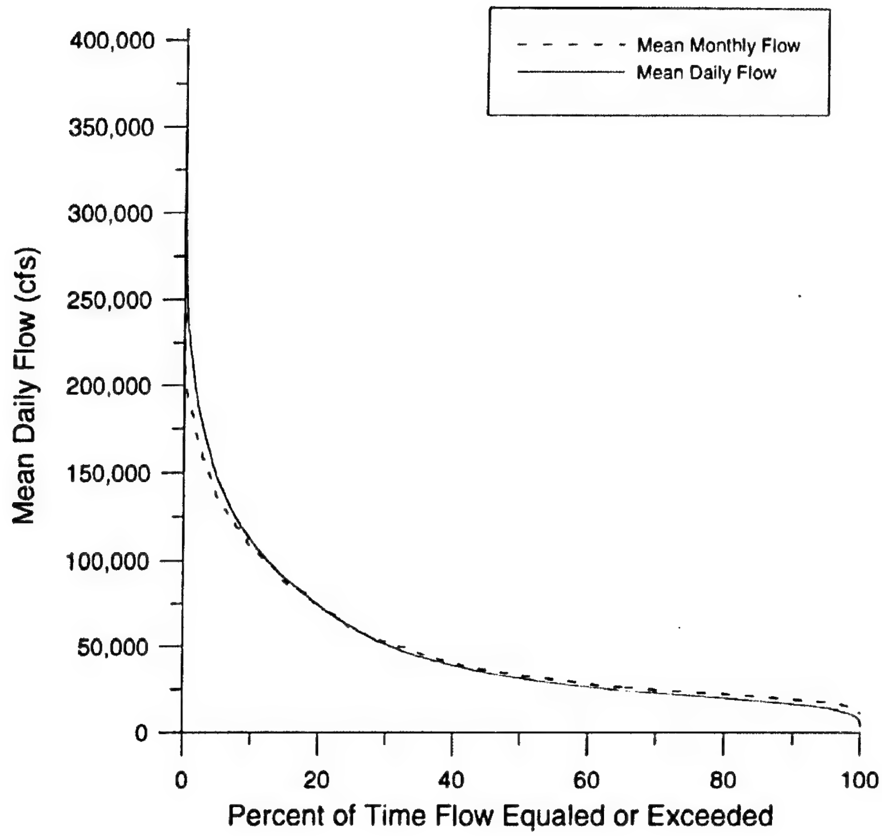


Figure 8-3. Flow Duration Curves Based on Mean Monthly and Mean Annual Flows at Lower Granite Dam

Table 8-1. Lower Granite Flow Exceedances

Percent of Time Equaled or Exceeded	Discharge (cfs)
10	111,500
20	74,260
50	31,710
80	19,900
90	16,680

Table 8-2. Elevation Boundary Conditions Used in the Simulations

Boundary	Elevation
Lower Granite Dam	738 feet
Little Goose Dam	635 feet
Lower Monumental Dam	540 feet
Ice Harbor Dam	440 feet
Columbia-Snake River Confluence	341 feet

8.4 Criteria for Initiation of Sediment Movement

The sediment mobility criteria are based on American Society of Civil Engineers (ASCE, 1975) standards, and provide an estimate of the mean velocity and bed shear stress required to initiate movement. Table 8-3 lists the critical values of velocity and bed shear stress for each sediment size class. The velocity criteria are based on the classical Hjulstrom curve. The shear stress criteria are based on the Shields curve, which does not apply to cohesive sediments (less than 0.0625 millimeters). Site-specific tests are usually required to estimate the critical shear stress for cohesive sediments.

Table 8-3. Sediment Size Classification and Criteria for Initial Movement

Class Name	Size (mm)	Critical Erosion Velocity (ft/sec)	Critical Shear Stress (lb/ft^2)
Boulders	256.0000	12.0	5.20000
Cobbles	64.00000	9.0	1.30000
Very Coarse Gravel	32.00000	7.3	0.62000
Coarse Gravel	16.00000	5.0	0.32000
Medium Gravel	8.00000	3.2	0.16000
Fine Gravel	4.00000	2.0	0.07000
Very Fine Gravel	2.00000	1.3	0.02950
Very Coarse Sand	1.00000	0.8	0.01230
Coarse Sand	0.50000	0.7	0.00540
Medium Sand	0.25000	0.6	0.00364
Fine Sand	0.12500	0.7	0.00306
Very Fine Sand	0.06250	0.8	0.00257
Coarse Silt	0.03100	1.1	
Medium Silt	0.01600	1.6	
Fine Silt	0.00800	2.2	
Very Fine Silt	0.00400	3.5	
Coarse Clay	0.00200	5.5	
Medium Clay	0.00100	8.0	
Fine Clay	0.00050	11.0	
Very Fine Clay	0.00024	14.0	
Colloids			

It should be noted that these criteria are not exact, and there is uncertainty with regard to the precise hydraulic conditions that initiate sediment movement, however, these criteria are used to indicate the representative conditions that will generally lead to the erosion of bed material of a given size class. The results in Section 9 are presented in terms of the critical velocities, since grain size distribution data are not available to modify the Shields criteria for non-uniform bed material.

8.5 Habitat Suitability Criteria for Spawning Fall Chinook Salmon

Areas of potentially suitable habitat for spawning fall chinook were determined by applying criteria for preferred spawning habitat to the hydrodynamic conditions simulated in model runs for impounded and unimpounded river conditions for the 50 percent exceedance flow (31,710 cfs). The criteria were the same as those used in a study by the U.S. Fish and Wildlife Service (USFWS) in 1999. For spawning chinook, suitable habitats had: 1) depth-averaged velocities between 1.3 and

6.4 feet per second; 2) depths between 1.3 and 21 feet; and 3) substrates categorized as gravel, cobble, gravel/cobble, cobble/gravel, and cobble/sand.

Point data from MASS2 simulations, including depth and depth-averaged velocity, were intersected with substrate data derived from pre-dam maps (Corps, 1934). The suitability criteria were applied to each point, and coded as "suitable" if all three criteria were met, and "unknown" if substrate data were not available at that point, but velocity and depth criteria were satisfied. All other points were classified as "unsuitable." These irregularly-spaced classified point data were then converted into a regularly-spaced, 40-foot grid, using ArcInfo. Statistics from this grid were used to calculate the area and potential suitability of spawning habitat for the 50 percent exceedance flow (31,710 cfs) for both the impounded and unimpounded river.

8.6 Habitat Suitability Criteria for Juvenile Fall Chinook Salmon

Areas of potential suitable habitat for spawning fall chinook were determined by applying criteria for preferred spawning habitat to the hydrodynamic conditions simulated in model runs for impounded and unimpounded river conditions for the 50 percent exceedance flow (31,710 cfs). The criteria were the same as those use in a study by USFWS in 1999. For juvenile fall chinook, suitable habitats had: 1) mean velocities less than 4 feet per second; 2) depths between 0.3 and 5.3 feet; and 3) were located within 81.7 feet of the shore.

ArcInfo was used to determine the areas within 81.7 feet of the shore, and those data intersect with MASS2 simulation point data for the 50 percent exceedance flow. The suitability criteria was applied to each point, and the point coded as "suitable" if all three criteria were met. Otherwise, they were classified as "unsuitable." The irregularly-spaced classified point data were then converted into a regularly spaced 40-foot ArcInfo grid. Statistics from this grid were used to calculate the area and suitability of potential rearing habitat for the 50 percent exceedance flow (31,710 cfs) for both the impounded and unimpounded river.

9. Results

The velocities and depths computed by the MASS2 model were used to compare the hydraulic and sediment mobility characteristics for impounded and unimpounded river conditions. Examples of figures showing spatial distributions for velocity, substrate particle size, and habitat at 10, 50, and 80 percent exceedance flows are presented in Annexes A, B, and C. The full set of figures for the entire lower Snake River can be viewed electronically on the Walla Walla District home page (http://www.nww.usace.army.mil).

9.1 Flow Conditions

Verification data for the model were not available for the unimpounded river cases. The MASS2 model has been extensively verified for current impounded conditions (Richmond et al., 1998). Figures 9-1 and 9-2 show comparisons between simulated and measured velocities in the area downstream of Lower Granite Dam. Although these are not strictly unimpounded river conditions, these results do show that the model is able to adequately represent velocities in shallow areas for current conditions.

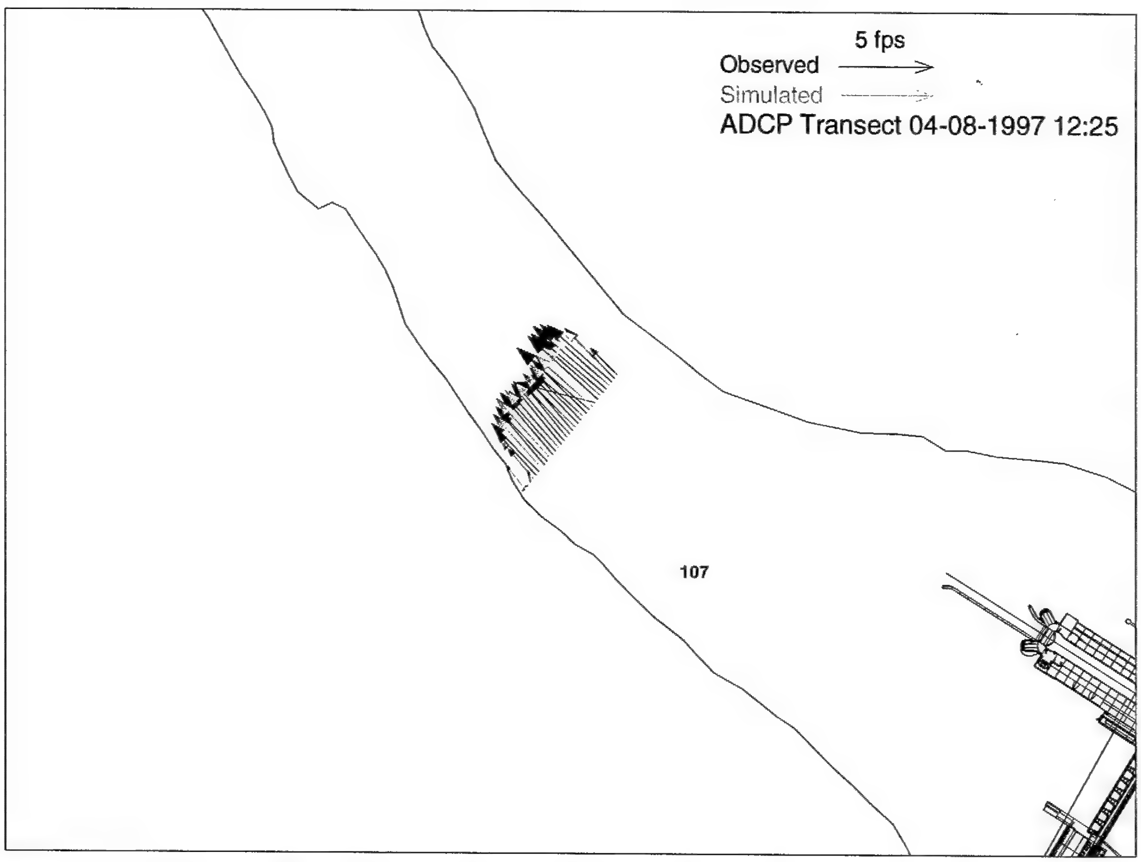


Figure 9-1. Comparison of Simulated and Measured Depth-averaged Velocities Near Snake River Mile 107 (downstream of Lower Granite Dam) for Impounded Conditions

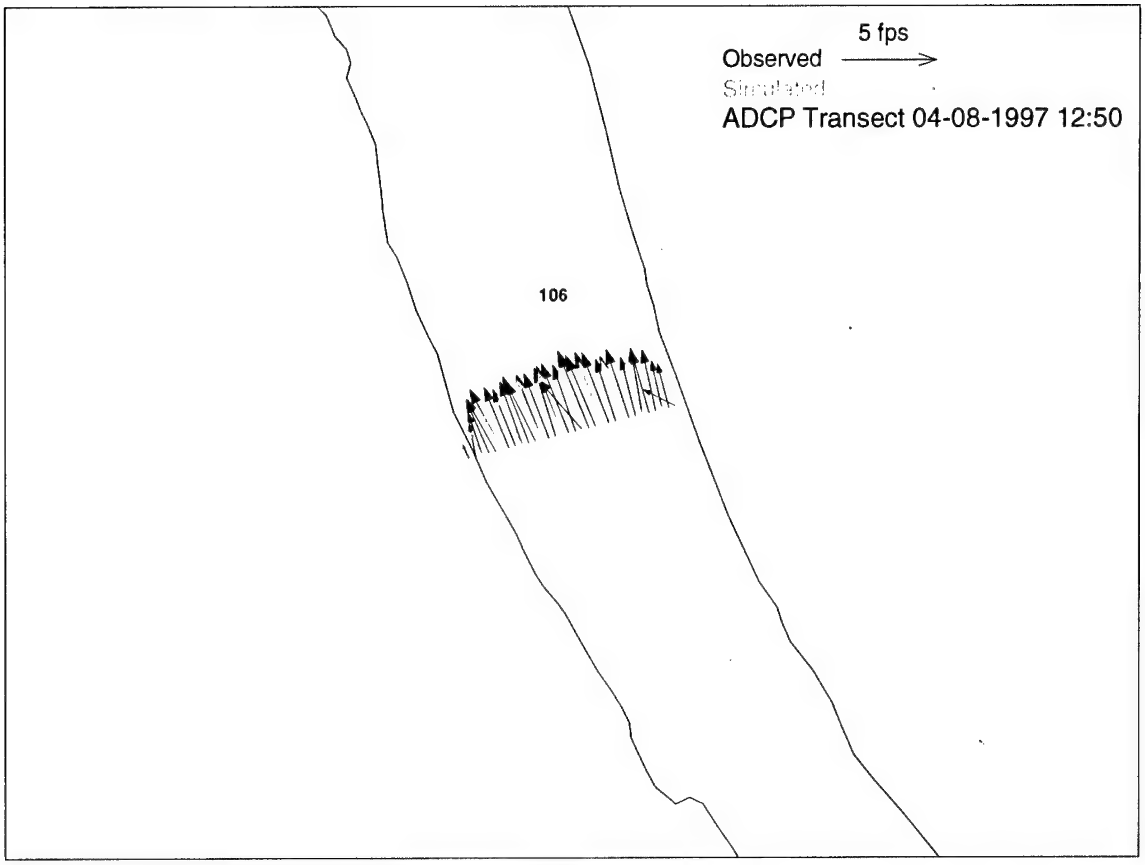


Figure 9-2. Comparison of Simulated and Measured Depth-average Velocities Near Snake River Mile 106 (downstream of Lower Granite Dam) for Impounded Conditions

Tables 9-1 and 9-2 compare the river surface areas and velocities for the impounded and unimpounded river cases. The unimpounded river has higher velocities and a more variable distribution of velocities.

Table 9-1. Comparison of River Surface Areas for Impounded and Unimpounded River Conditions

Region	Impounded River (Acres)	Unimpounded 10 Percent (Acres)	Unimpounded 50 and 80 Percent (Acres)
Lower Granite	7,541	3,255	2,816
Little Goose	9,310	4,592	3,749
Lower Monumental	5,803	3,450	3,124
Ice Harbor	7,954	4,290	3,558
McNary	1,788	1,810	1,988
Total	**32,395**	**17,397**	**15,236**

Note: These areas were derived from vector-based polygons rather than the grid-based areas derived from model output. Therefore, they are slightly different than the total area in the velocity distribution comparison table.

Table 9-2. Comparison of Simulated Velocity Distributions for the 10, 50, and 80 Percent Exceedance-flows

Exceedance	10 Percent		50 Percent		80 Percent	
Velocity (ft/sec)	Impounded (acres)	Unimpounded (acres)	Impounded (acres)	Unimpounded (acres)	Impounded (acres)	Impounded (acres)
0-0.5	9,839	176	26,210	711	31,012	1,670
0.5-1	7,936	173	4,633	1,050	1,472	1,171
1-2	8,483	463	1,656	1,625	135	2,855
2-3	3,498	942	120	2,649	0	3,608
3-4	1,681	938	0	3,424	0	2,855
4-5	829	1,496	0	2,707	0	1,607
5-6	235	2,558	0	1,632	0	835
6-7	118	3,592	0	837	0	413
7-8	0	3,497	0	405	0	171
8-9	0	2,224	0	161	0	71
9-10	0	900	0	61	0	24
10+	0	460	0	45	0	11
Total Area	**32,619**	**17,419**	**32,620**	**15,309**	**32,620**	**15,309**

Note: 111,500, 31,710, and 19,900 cfs, respectively, of the Impounded and Unimpounded River Conditions

9.2 Sediment Transport

Surveyed sediment ranges in Lower Granite Lake, obtained from the Corps, were used to estimate the amount of sediment available for transport shown in Figure 9-3. Sediment transport rates were estimated using the Toffaletti methods (ASCE, 1975). The following output from the long-term model simulations were used in the Toffaletti method: average velocity, friction slope, and hydraulic radius. The method required the selection of a representative water temperature, median sediment size (D50), and settling velocity. A water temperature of 10°C (50°F), and a D50 of 0.5 millimeters (medium sand) were selected and used at each cross section. The transport rates computed from a medium sand will be smaller than those computed for a fine sand or silt. Therefore, the removal time estimates should be conservative in that a longer removal time will be computed for portions of the reservoir that have bed sediments composed of fine sands and silts.

An estimate of the time to remove the available sediment from Lower Granite Lake was calculated using the estimated available volume and transport rate. The sediment transport rate that was exceeded 50 percent of the time was used in these calculations. As shown in Figure 9-4, this estimate indicates that the time to remove the available sediment will be less than 5 years over the majority of Lower Granite Lake. This is in agreement with observations made during the 1992 drawdown test (Corps, 1993). Sediment transport rates measured during the drawdown test were comparable to the computed rates of about 44,000 tons per day at RM 137 (Figure 9-2). In addition, the drawdown test demonstrated that fine sediments were rapidly mobilized and transported, indicting the non-cohesive nature of post-impounded sediments. Note that the above removal time estimate for Lower Granite Lake applies only to the bankfull area of the river. Zones beyond the bankfull shoreline will require a longer time (less frequent flows) to return to pre-dam conditions. Wind and rain erosion and, where tributaries enter, channel incision processes will also affect these zones.

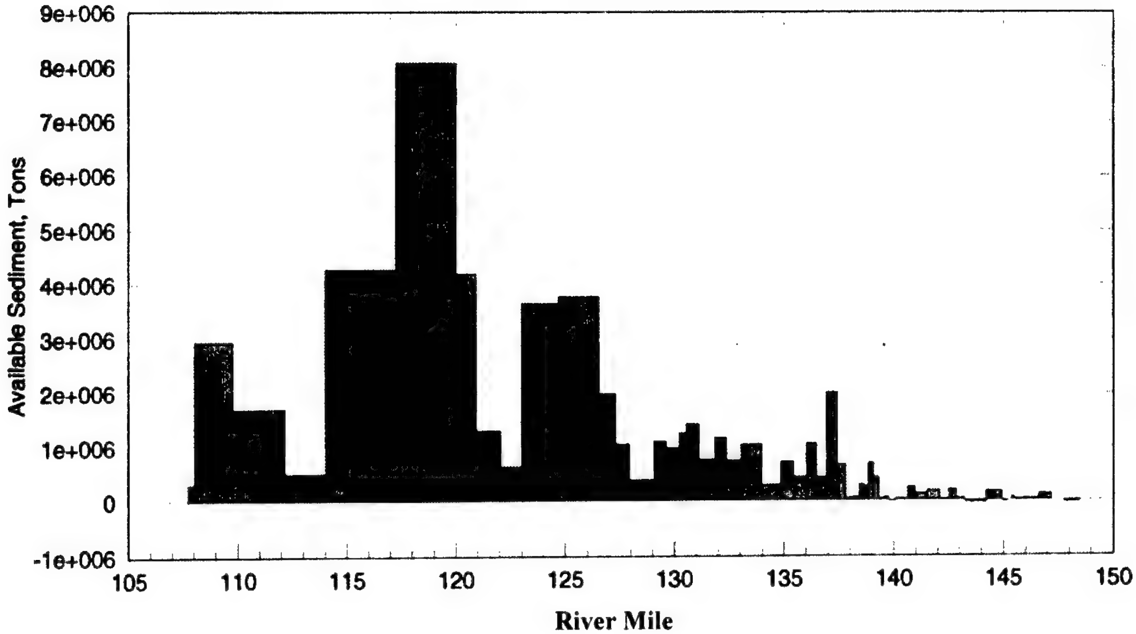


Figure 9-3. Estimated Available Sediment Along the Lower Granite Lake

Based on these calculations and the drawdown test field observations, the analysis compares current, impounded conditions to an unimpounded equilibrated condition 5 to 10 years after dam breaching. Again, the 1934 bathymetry is assumed to be representative of these future conditions.

Sediment mobility is estimated by using modeled velocities in conjunction with general criteria for the initiation of sediment movement presented in Section 9.4. Table 9-3 compares the estimated number of acres of river that would be capable of mobilizing different sized bed material. Except during high flows, impounded conditions are incapable of transporting significant amounts of material coarser than medium sand. The higher velocities in the dam-breaching alternative are able to mobilize material into the coarse gravel size range.

Recent work in gravel-bedded rivers suggests that these classic criteria for the initiation of sediment transport do not adequately represent field conditions. In some gravel-bedded rivers, the shear stress necessary to initiate motion is about twice the classic critical shear stress (Church et al., 1998), and the initial-motion shear stress can be up to three times the shear stress thresholds of final motion (Reid et al., 1985). Figures 9-5 and 9-6 show how the expected sediment in motion might change under a modified critical shear stress criteria that is 1.5 times the classic criteria for the 10 and 50 percent exceedance flow for materials coarser than fine gravels, respectively. As is demonstrated in these figures and Table 9-4, this modified criteria greatly reduced the area that would actively transport sediment larger than cobbles, although it would not change the area able to transport finer materials (including clays).

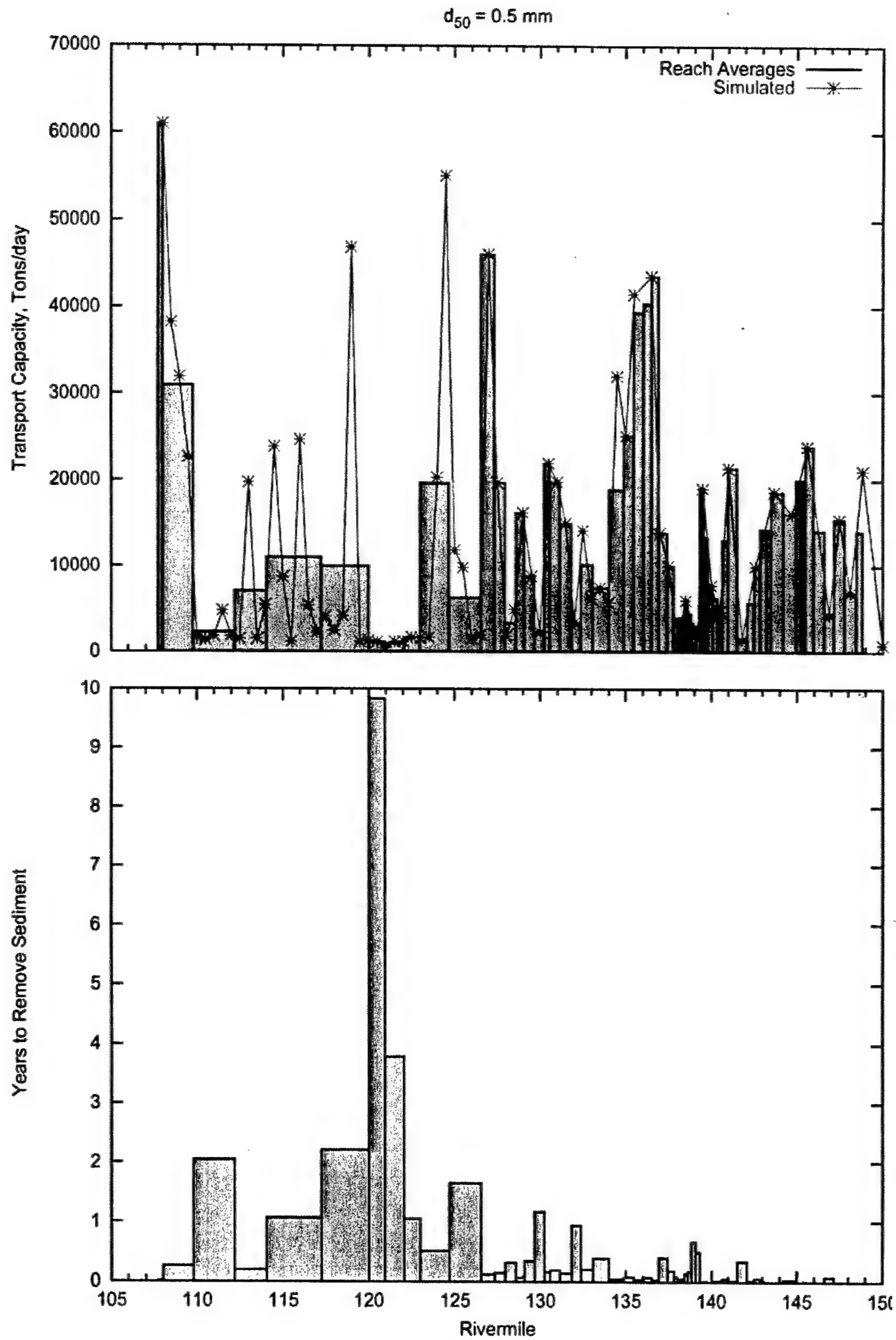


Figure 9-4. Estimates of Sediment Removal Time in Lower Granite Lake, Given a Sediment D50 of 0.5 Millimeters

Note: The upper graph shows simulated transport rates exceeded 50 percent of the time in Lower Granite Lake.

Table 9-3. Comparison of Sediment Mobility at the 10, 50, and 80 Percent Exceedance-flows (111,500, 31,710, and 19,900 cfs, Respectively) for the Impounded and Unimpounded River

Exceedance	10 Percent		50 Percent		80 Percent	
Sediment in Transport	Impounded (acres)	Unimpounded (acres)	Impounded (acres)	Unimpounded (acres)	Impounded (acres)	Unimpounded (acres)
Boulders	0	40	0	10	0	3
Cobbles	0	1,361	0	106		36
Coarse Gravels/Coarse Clay	354	13,230	0	3,360	0	1,667
Medium Gravel/Very Fine Silt	2,622	15,498	0	8,604	0	5,353
Fine Gravel/ Fine Silt	6,361	16,606	120	11,922	0	9,613
Medium Sand	21,056	17,209	4,795	14,396	959	13,352
Negligible Sediment Transport	11,564	210	27,825	913	31,661	1,956

9.3 Fall Chinook Habitat Suitability

Before addressing the results of the potential habitat suitability and availability analysis, it is critical to ascertain if the underlying data is of adequate resolution and quality to support such analyses. Bathymetric data for these studies were derived from the 1934 survey (Corps, 1934). These data consist of cross-sections of closely-spaced point data of 1/10th foot vertical resolution within the 1934 channel, and 5-foot contours outside the channel. Therefore, much better resolution of depth is expected for areas within the 1934 channel (i.e., the "unimpounded" river of this study) than outside the 1934 channel (i.e., between the shores of the current reservoirs and the unimpounded river), where the depth resolution is much coarser.

The spawning habitat criteria span a broad range of conditions that are met over large areas. The spawning habitat criteria require that depths are between 1.3 and 21 feet, with velocities between 1.3 and 6.4 feet per second. This range of depths is well resolved by the bathymetric data for impounded and unimpounded conditions, and the depth criteria are met over large spatial areas for both the impounded and unimpounded cases (24 and 94 percent of surface area, respectively). Sediment data were collected during pre-dam conditions, and little data exists for large spatial areas to determine changes in bed composition since the construction of the dams. Although the lower limit of velocity, 1.3 feet per second, is sufficient to mobilize and subsequently remove sand, it is not sufficient to mobilize finer materials such as medium silt or clays. Therefore, if sediment data is deemed representative of current conditions, the analysis should adequately represent potential spawning habitat availability for both the impounded and unimpounded conditions.

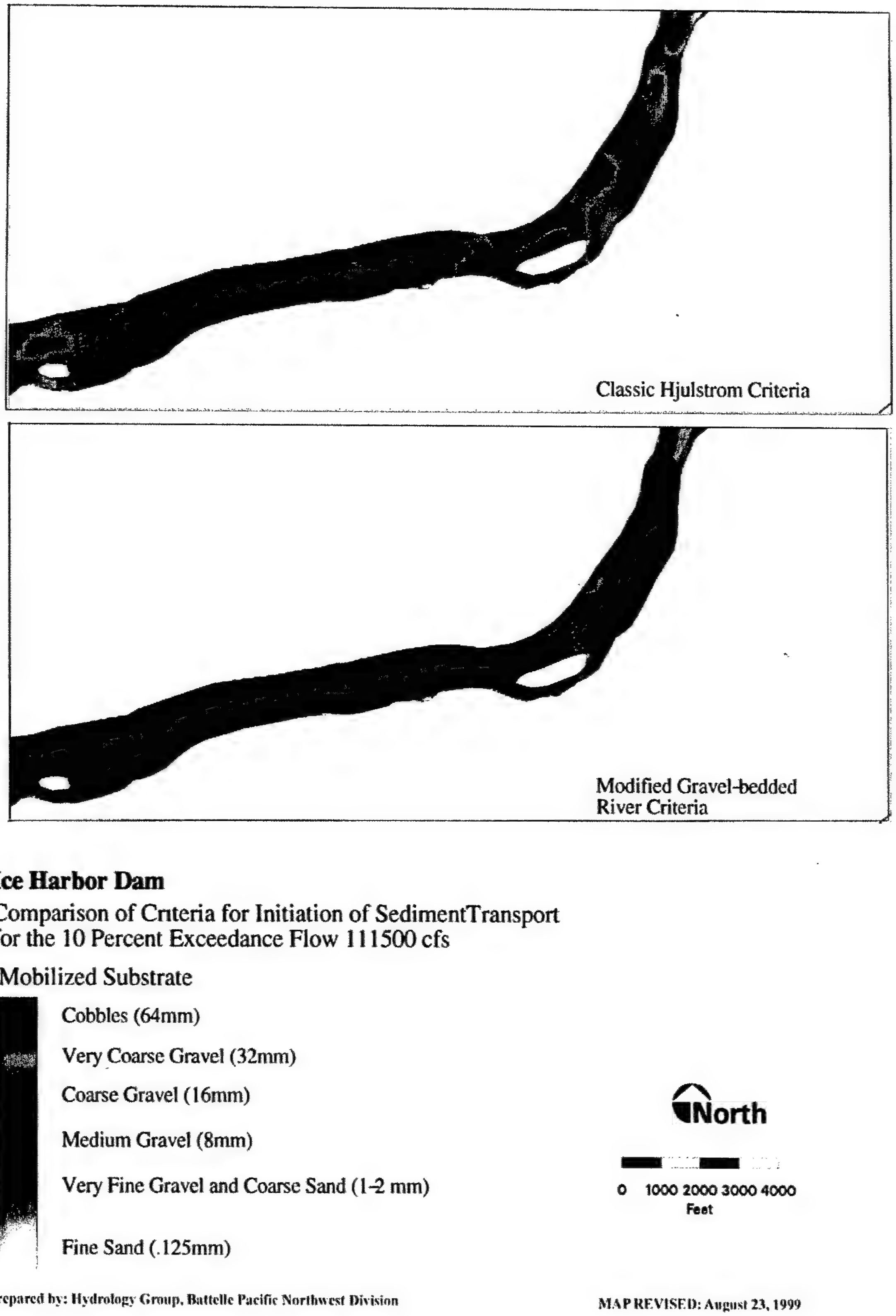
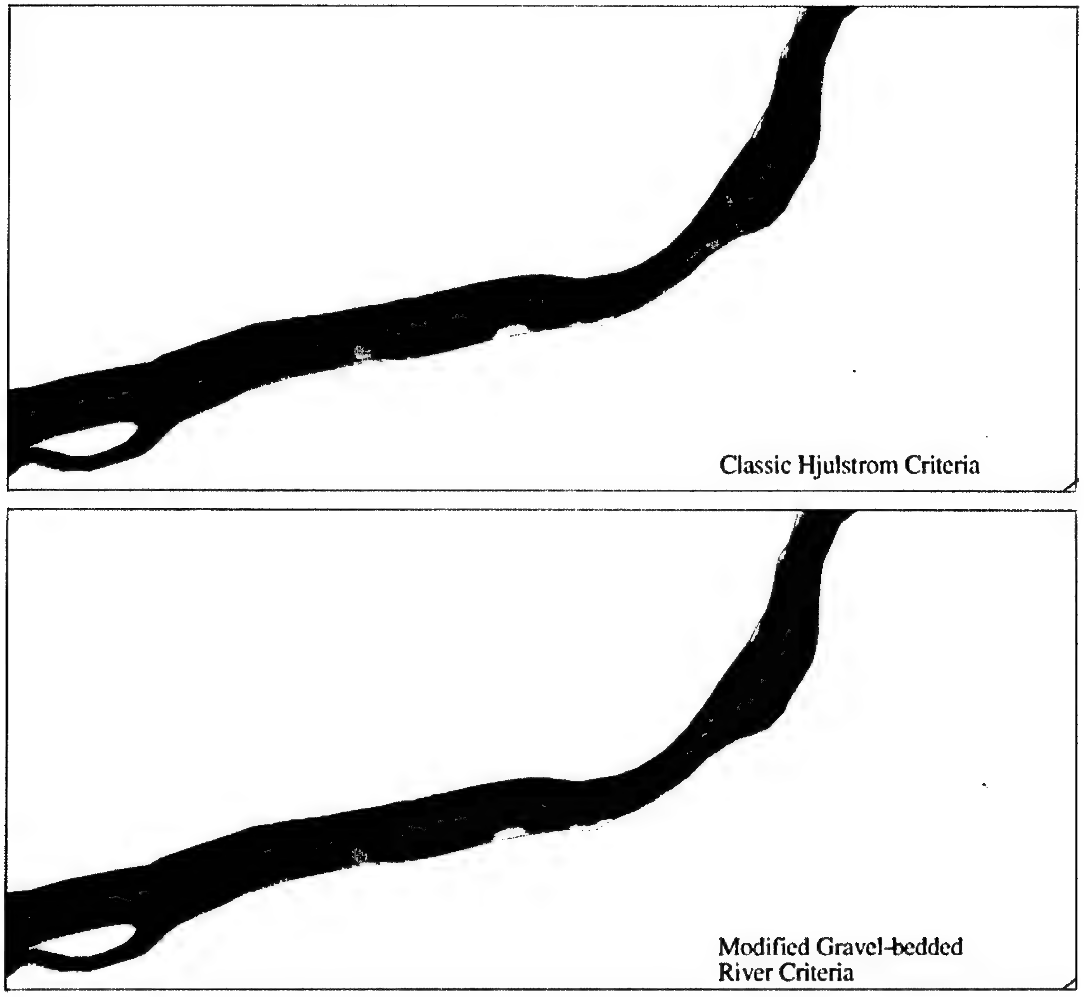


Figure 9-5. Comparison of Mobilized Sediment for the 10 Percent Exceedance-flow Near Ice Harbor Dam for the Unimpounded River



Ice Harbor Dam

Comparison of Criteria for Initiation of SedimentTransport
for the 50 Percent Exceedance Flow 31710 cfs

Mobilized Substrate

Cobbles (64mm)

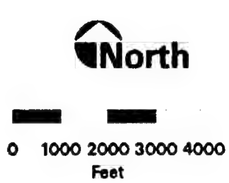
Very Coarse Gravel (32mm)

Coarse Gravel (16mm)

Medium Gravel (8mm)

Very Fine Gravel and Coarse Sand (1-2 mm)

Fine Sand (.125mm)



Prepared by: Hydrology Group, Battelle Pacific Northwest Division

MAP REVISED: August 23, 1999

Figure 9-6. Comparison of Mobilized Sediment for the 50 Percent Exceedance-flow Near Ice Harbor Dam for the Unimpounded River

Table 9-4. Comparison of Sediment Mobility Applying a Criteria More Appropriate for Gravel-bedded Rivers for the 10 and 50 Percent Exceedance-flows (111,500 and 31,710 cfs, Respectively) for the Impounded and Unimpounded River

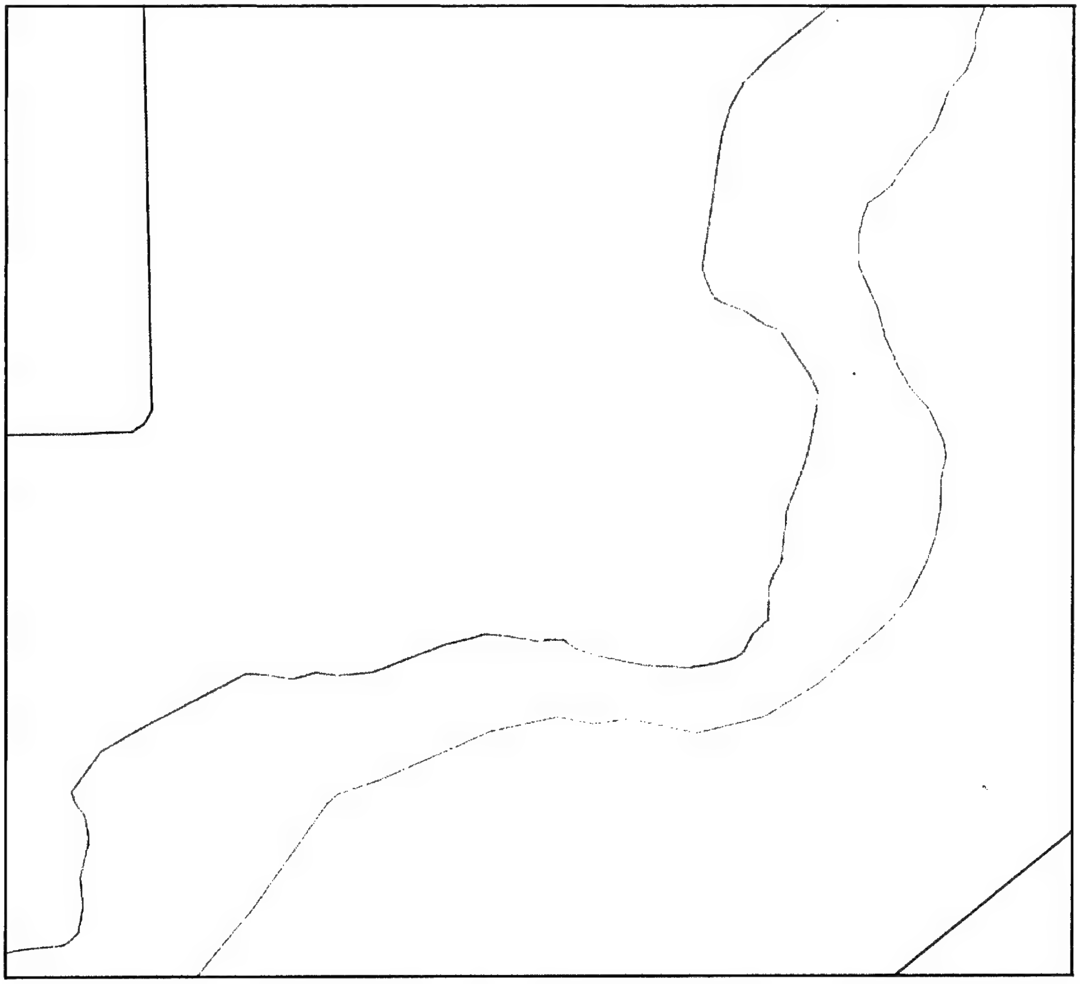
Exceedance	10 Percent		50 Percent	
Sediment in Transport	Impounded (acres)	Unimpounded (acres)	Impounded (acres)	Unimpounded (acres)
Boulders	0	0	0	0
Cobbles	0	8	0	4
Coarse Gravels	1	5,229	0	432
Medium Gravel/Clay	317	13,230	0	3,142
Fine Gravel/Very Fine Silt	1,880	15,236	0	7,545
Very Fine Gravel	6,154	16,727	120	11,922
Medium Sand	21,056	17,209	4,795	14,396
Negligible Sediment Transport	11,564	210	27,825	913

The area of potential suitable spawning habitat changes greatly between impounded and unimpounded conditions. There are 226 and 3,521 acres of potential suitable habitat for the impounded and unimpounded conditions, respectively (Table 9-5). When the areas that meet depth and velocity criteria, but have missing substrate data, are included, the total area of potential spawning habitat is 1.3 percent and 32 percent of the surface area of the river for the impounded and unimpounded rivers, respectively. The area for suitable habitat for the impounded river would decrease if the sediment data were deemed inadequate. This marked difference in areas of potential suitable habitat for the impounded and unimpounded river is demonstrated for an area above Ice Harbor Dam in Figures 9-7 and 9-8. Much of the suitable spawning habitat for the impounded river is located in the dam tailwaters, and the largest of these areas is below Ice Harbor Dam (Figure 9-9).

Table 9-5. Acres of Potential Suitable Fall Chinook Spawning and Rearing Habitat for the 50 Percent Exceedance-flow for the Impounded and Unimpounded River

Habitats	Impounded (acres)	Unimpounded (acres)
Potential Suitable Spawning Habitat	226	3,521
Potential Possible Spawning Habitat (depth and velocity criteria met, but substrate unknown)	176	1,396
Unsuitable Spawning Habitat	32,177	10,392
Potential Suitable Rearing Habitat	652	889

In addition to spawning habitat potential for fall chinook salmon, the availability and suitability of rearing habitat are critical factors. The rearing habitat criteria is much more restrictive than spawning habitat criteria, and requires that depths are between .3 and 5.3 feet, velocities are less than 4 feet per second, and they must be located within 81.7 feet from shore. This narrow range of depths is adequately resolved within the 1934 channel, but not for the narrow margins near



Above Ice Harbor Dam

— Fall Chinook Spawning Habitat Suitability for the Impounded River
for the 50 Percent Exceedance Flow 31710 cfs

Unsuitable Habitat

Unknown (Velocity and Depth Criteria met, but Substrate Unknown)

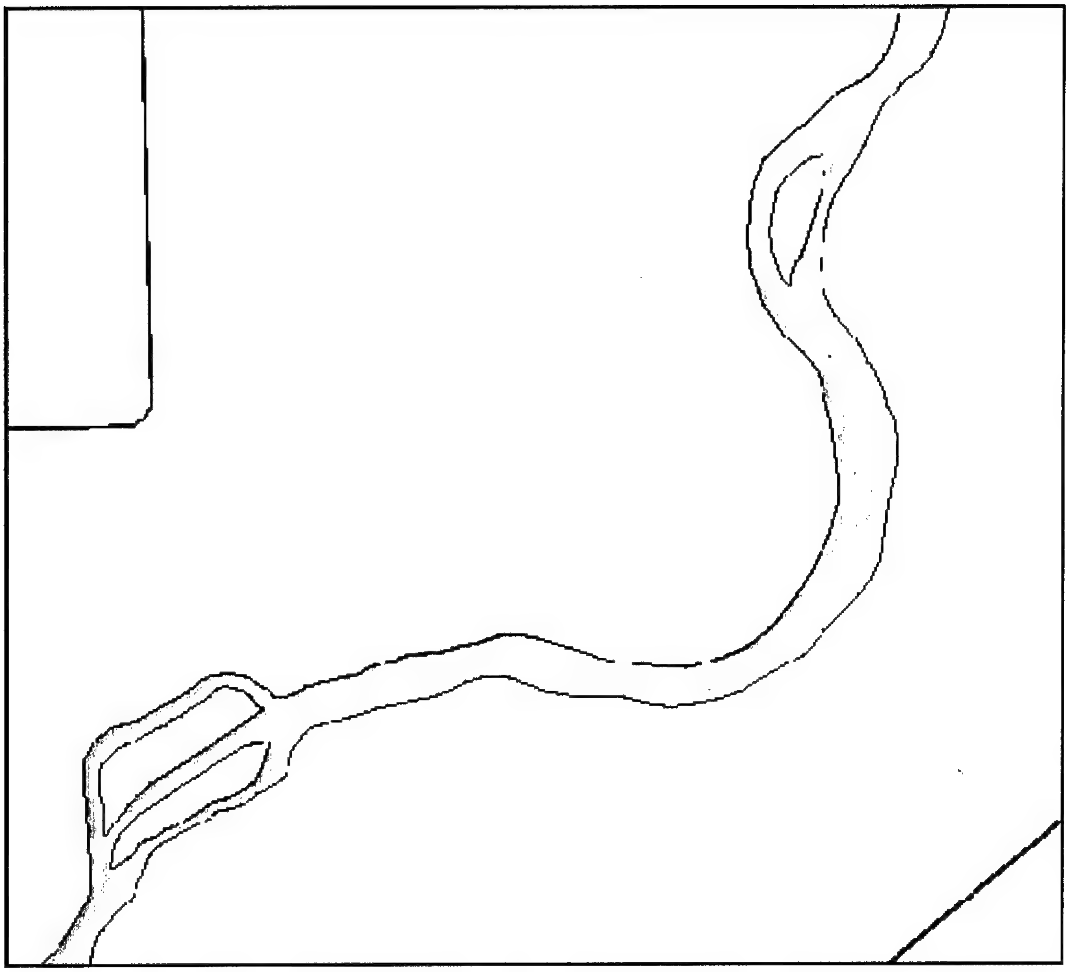
Suitable Habitat

North

0 1000 2000 3000 4000
Feet

Figure 9-7. Suitable Fall Chinook Spawning Habitats Above Ice Harbor Dam for the Impounded River

shorelines for the impounded river. In addition, grid spacing within the numerical model has a nearshore spacing of nodes of about 40 feet, with nodes spaced about 80 to 90 feet in the cross-stream, and about 200 feet in the downstream direction. Consequently, the resulting difference in area of potential suitable rearing habitat of 652 and 89 acres (see Table 9-5, and Figures 9-10 and 9-11 for the impounded and unimpounded rivers) should be viewed with caution. This difference in suitable rearing habitat is supported qualitatively by the difference in shoreline length of 285 and 306 miles (for the impounded and unimpounded rivers, respectively). This increase is the result of increased shoreline complexity with lower water levels and the emergence of midstream islands and bars.



Above Ice Harbor Dam

Fall Chinook Rearing Habitat Suitability for the Unimpounded River
for the 50 Percent Exceedance Flow 31710 cfs

☐ **Unsuitable Habitat**

☐ **Unknown (Velocity and Depth Criteria met, but Substrate Unknown)**

☐ **Suitable Habitat**

North

0 1000 2000 3000 4000
Feet

Figure 9-8. Habitat Suitability for Fall Chinook Spawning Habitats Above Ice Harbor Dam for the Unimpounded River

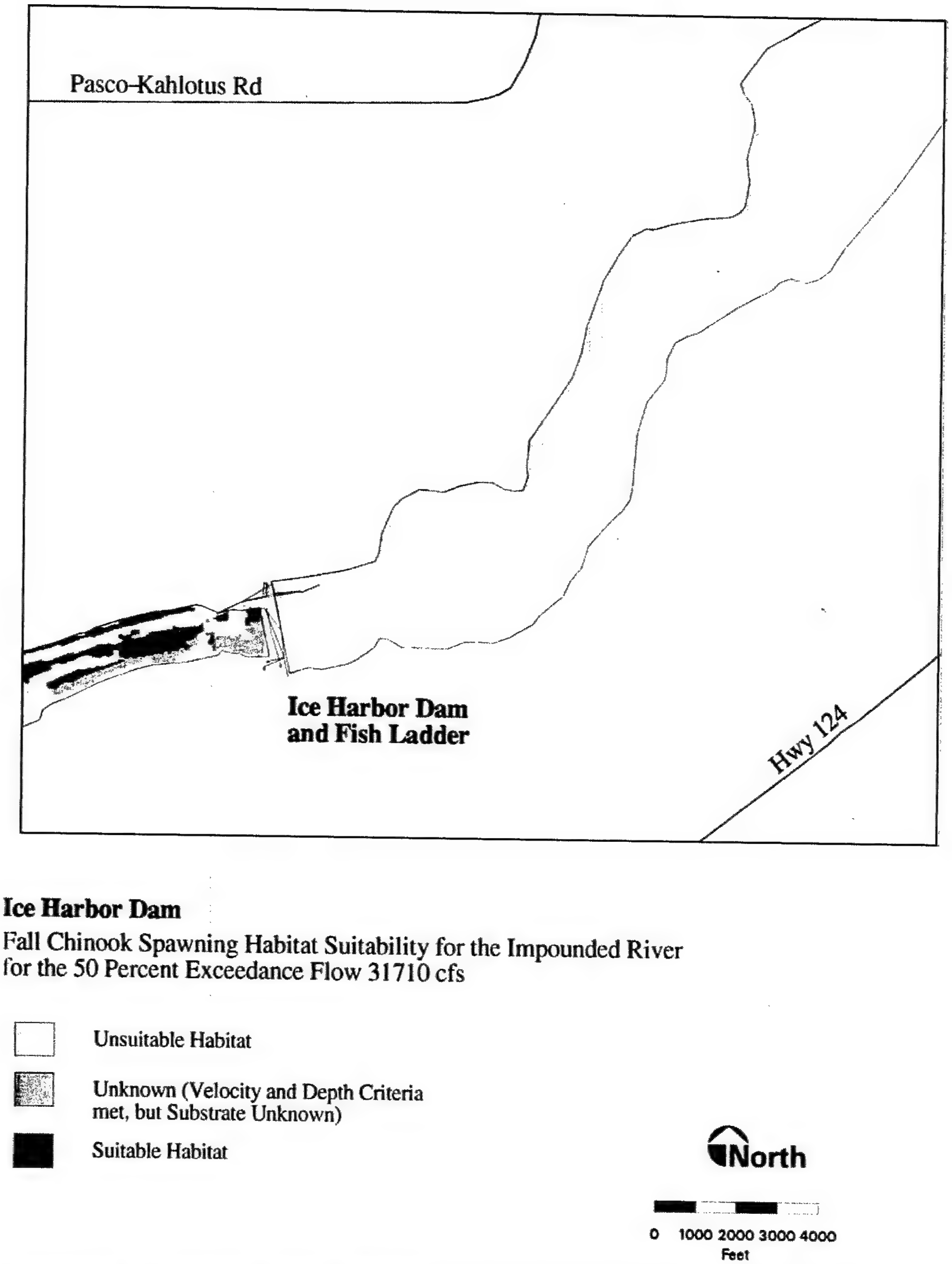
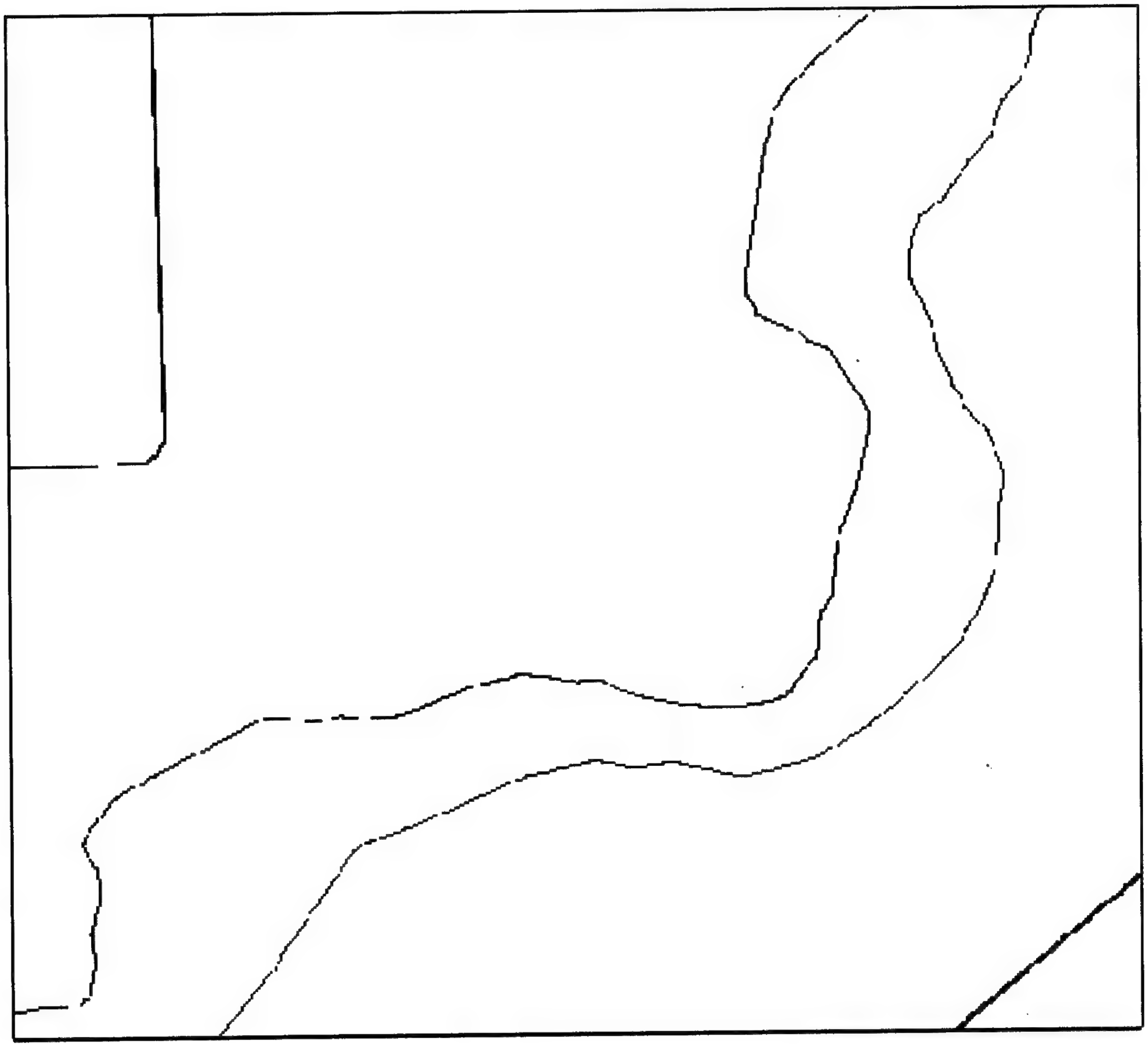


Figure 9-9. Potential Habitat Suitability for Fall Chinook Spawning Habitats Near Ice Harbor Dam for the Impounded River



Above Ice Harbor Dam

Fall Chinook Rearing Habitat Suitability for the Unimpounded River
for the 50 Percent Exceedance Flow 31710 cfs

Unsuitable Habitat

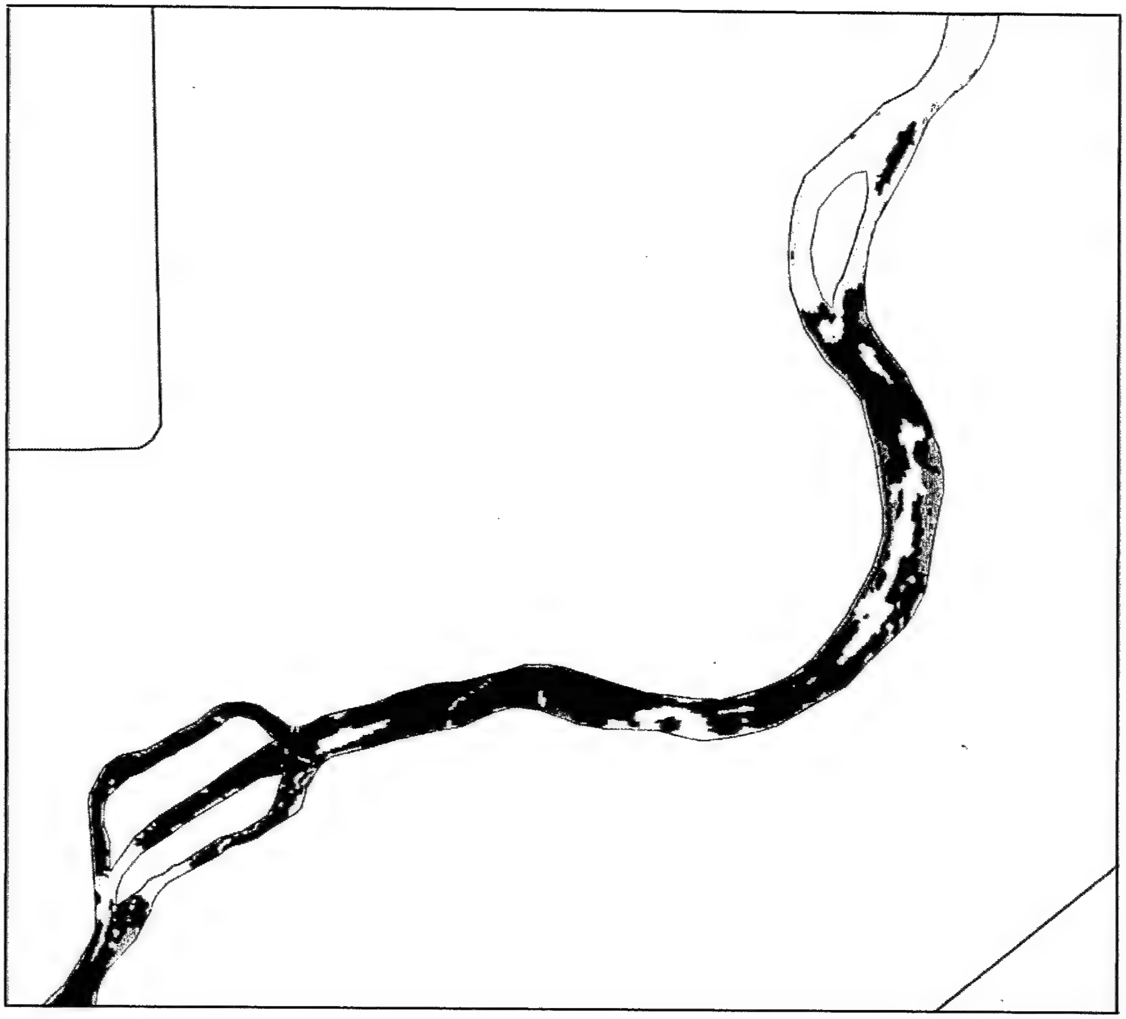
Unknown (Velocity and Depth Criteria met, but Substrate Unknown)

Suitable Habitat

North

0 1000 2000 3000 4000
Feet

Figure 9-10. Potential Habitat Suitability for Fall Chinook Rearing Habitats Above Ice Harbor Dam for the Impounded River



Above Ice Harbor Dam

Fall Chinook Spawning Habitat Suitability for the Unimpounded River
for the 50 Percent Exceedance Flow 31710 cfs

- Unsuitable Habitat
- Unknown (Velocity and Depth Criteria met, but Substrate Unknown)
- Suitable Habitat

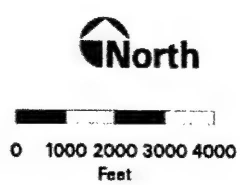


Figure 9-11. Potential Habitat Suitability for Fall Chinook Rearing Habitats Above Ice Harbor Dam for the Unimpounded River

This page is intentionally left blank.

10. Conclusions and Recommendations

The results of the hydraulic simulations showed that, for the 50 percent exceedance flow (31,710 cfs), the natural river conditions are characterized by a wider range of depth-averaged velocities. For impounded conditions, the majority of river area had velocities less than 2 feet per second. By comparison, the natural river condition shows that most of the velocities are in the range of 1 to 8 feet per second. The natural river conditions case also shows that velocities will be more evenly distributed over that range.

Based on critical velocity criteria, simulations for the 50 percent exceedance flow for impounded conditions showed that mainly sediments finer than a medium sand (0.25-millimeter diameter) would be mobilized or remain in transport. In the natural river case, the same flow would mobilize medium (16 millimeters) to coarse gravel (64 millimeters) or finer materials over most of the river channel. Thus, for typical flow conditions, most of the fine sediments that have been deposited in the lower Snake River reservoirs will be remobilized and transported downstream. The dominance of coarse material is consistent with current observations of substrate composition in the areas immediately downstream of the dams.

Because the lower Snake River hydrograph is affected by water and land management practices throughout the watershed, and is controlled by upstream dams, it is certain that the river channel will not be restored to its pristine pre-development condition by breaching the four lower Snake River dams. Exactly how the resultant channel bed would differ from the original channel bed is unknown. Recent research on gravel-bedded streams indicates that the bed shear stress may have to be three times higher to initiate movement in a substrate composed of coarse materials interlaced with fine sediments, as compared to the uniform bed criteria. The potential decreased mobility of the coarse materials (larger than fine gravel) was examined using a velocity criteria 1.5 times higher than the uniform criteria. Under those conditions, 10 percent exceedance (111,500 cfs) flows may be required to mobilize the same area of coarse materials, as was the case using the uniform criteria at the 50 percent (31,170 cfs) exceedance flow.

Additional information on the evolution of the channel bed would be useful to understand the dynamics of the transition between impounded to natural river conditions. Such simulations would also be useful for designing a field program to monitor and evaluate river conditions if the dams were breached. As stated in the introduction, such simulations would require additional data that would include bathymetric surveys, measurements of sediment grain size distributions in the channel bed, bed sediment depth, transport properties for cohesive sediments, and tributary sediment loads.

This page is intentionally left blank.

11. Literature Cited

ASCE. 1975. Sedimentation Engineering. American Society of Civil Engineers.

Bagnold, R. A. Bed load transport by natural rivers, Water Resources Research, 13(2), 303-312, 1977.

Baker, V. R. and R. C. Bunker. Cataclysmic late Pleistocene flooding from glacial Lake Missoula: A review. Quaternary Science Reviews, 4, 1-41, 1985.

Battelle and USGS. Assessment of the impacts of development and operation of the Columbia River hydroelectric system on mainstem riverine processes and salmon habitats. Draft report to the Bonneville Power Administration, Portland, Oregon, 1999.

Bonneville Power Administration. 1993. Adjusted streamflow and storage 1928-1989: Columbia River and coastal basins. Report and technical appendices prepared by A.G. Crook Co, for BPA, 1993.

Carling, P. 1988. The concept of dominant discharge applied to two gravel-bed streams in relation to channel stability thresholds. Earth Surface Processes and Landforms, 13, 355-367.

Church, M. A. and K. Rood. Catalogue of alluvial river channel regime data, 1.0. Department of Geography, University of British Columbia, Vancouver, BC, Canada, 1983.

Church, M., M. Hassan, and J. Wolcott. 1998. Stabilizing self-organized structures in gravel-bed stream channels: field and experimental observations. Water Resources Research.

Corps (U.S. Army Corps of Engineers). 1934. Snake River, Washington-Idaho, Mouth to Oregon-Washington line. Survey Map Set, 154 Sheets. U.S. Army Corps of Engineers, U.S. Engineer Office, Portland, Oregon. In the possession of USACE, Walla Walla District, Walla Walla, Washington.

Corps. 1993. 1992 reservoir drawdown test, Lower Granite and Little Goose Dams. Technical report, U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington.

Corps. 1995. Biological Plan: Lower Snake River drawdown technical report, appendix Gm in Columbia River salmon mitigation analysis, system configuration study, phase 1. Technical report, U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington. Prepared for the U.S. Army Corps of Engineers, Walla Walla District.

Dauble, D. D. and D. R. Geist. Comparison of mainstem spawning habitats for two populations of fall chinook salmon in the Columbia River Basin. Regulated Rivers: Research and Management, In Press.

Dauble, D.D. and D.G. Watson. 1997. Status of fall chinook salmon populations in the mid-Columbia River, 1948-1992. North American Journal of Fisheries Management, 17(2), 283-300, 1997.

Davis, W. M. The geographic cycle. Geographic Journal, 14, 481-504, 1899.

Fulton, L. A. Spawning areas and abundance of chinook salmon (Oncorhynchus tshawytscha) in the Columbia River basin: Past and present. Special scientific report: Fisheries 571, 26 pp., U. S. Fish and Wildlife Service, Washington, D. C., 1968

Fulton, L. A. Spawning areas and abundance of steelhead trout and coho, sockeye, and chum salmon in the Columbia River basin: Past and present. Special scientific report: Fisheries 618, U. S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Washington, D. C., 1970.

Geist, D. R. and D. D. Dauble. Redd site selection and spawning habitat use by fall chinook salmon: the importance of geomorphic features in large rivers. Environmental Management, 22(5), 655-669, 1998.

Hanrahan, T., D. Neitzel, M. Richmond, and K. Hoover. 1998. Assessment of drawdown from a geomorphic perspective using geographic information systems, lower Snake River, Washington. Technical report, Pacific Northwest National Laboratory, PO Box 999, Richland, Washington. Prepared for the U.S. Army Corps of Engineers, Walla Walla District.

Hey, R. D. Stable river morphology, in Applied fluvial geomorphology for river engineering and management, edited by C. R. Thorne, R. D. Hey, and M. D. Newson, pp. 223-236, John Wiley and Sons, Chichester, 1997.

Hey, R. D. and G.L. Heritage. 1988. Dominant discharge in alluvial channels. In Proceedings of an International Conference on Fluvial Hydraulics, pp. 143-148, Budapest.

Hey, R. D. and C. R. Thorne. Stable channels with mobile gravel beds. Journal of Hydraulic Engineering, 112, 671-689, 1986.

Hooke, J. M. Styles of channel change, in Applied fluvial geomorphology for river engineering and management, edited by C. R. Thorne, R. D. Hey, and M. D. Newson, pp. 237-268, John Wiley and Sons, Chichester, 1997.

Hoopa Valley Tribe. Trinity River maintenance flow study, Final Report. Prepared by McBain & Trush, Arcata, CA, 1997.

Independent Scientific Group. Return to the river: Restoration of salmonid fishes in the Columbia River ecosystem. Northwest Power Planning Council, Portland, OR, 1996.

Johnson, B. R. and G. L. Raines. Digital representation of the Idaho state geologic map: A contribution to the Interior Columbia River Basin Ecosystem Management Project. Open File Report 95-690, U. S. Geological Survey, 1996.

Jones, M. and H. Seitz. 1980. Sediment transport in the Snake and Clearwater Rivers in the vicinity of Lewiston, Idaho. Technical Report Open-File Report 80-690, U.S. Geological Survey.

Jowett, I. G. A method for objectively identifying pool, run, and riffle habitats from physical measurements. New Zealand Journal of Marine and Freshwater Research, 27(2), 241-248, 1993.

Kellerhals, R. and M. Church. The morphology of large rivers: characterization and management, edited by D. P. Dodge, pp. 31-48, 1989.

Kellerhals, R., M. Church, and D. I. Bray. Classification and analysis of river processes. Journal of the Hydraulics Division, Proceedings of the American Society of Civil Engineers, 102(HY7), 813-829, 1976.

Kellerhals, R., C. R. Neill, and D. I. Bray. Hydraulic and geomorphic characteristics of rivers in Alberta. Research Council of Alberta, Edmonton, Alberta, Canada, 1972, 54 pages.

Knighton, D. Fluvial forms and processes. Edward Arnold, New York, NY, 218 pages, 1984.

Leopold, L. B. and M. G. Wolman. River channel patterns: Braided, meandering, and straight. U. S. Geological Survey Professional Paper 282-B, 1957.

Leopold, L. B., M. G. Wolman, and J. P. Miller. Fluvial processes in geomorphology. W. H. Freeman and Co., San Francisco, CA, 522 pages, 1964.

Lorenz, C. M., G. M. Van Dijk, A. G. M. Van Hattum, and W. P. Cofino. Concepts in river ecology: Implications for indicator development. Regulated Rivers: Research and Management, 13, 501-516, 1997.

Montgomery, D. R. and J. M. Buffington. Channel classification, prediction of channel response, and assessment of channel condition. Report TFW-SH10-93-002, Washington State Timber/Fish/Wildlife Agreement, Seattle, WA, 1993.

National Marine Fisheries Service. Biological Opinion on operation of the Federal Columbia River Power System. National Marine Fisheries Service, Seattle, WA, 1995.

National Marine Fisheries Service. A supplemental biological opinion to the March 2, 1995, Biological Opinion on operation of the Federal Columbia River Power System. National Marine Fisheries Service, Seattle, WA, 1998.

O'Connor, J. E. Hydrology, hydraulics, and geomorphology of the Bonneville Flood. Special paper 274, Geological Society of America, Boulder, CO, 1993.

Perkins, M. and M. Richmond. 1999. Long-term, one-dimensional simulation of lower Snake River temperatures for natural river and current conditions. Technical report, Pacific Northwest National Laboratory, PO Box 999, Richland, Washington. Prepared for the U.S. Army Corps of Engineers, Walla Walla District.

Quigley, T. M. and S. J. Arbelbide. An assessment of ecosystem components in the interior Columbia basin and portions of the Klamath and Great Basins: Volume 1. Gen. Tech. Rep. PNW-GTR-405, U. S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR, 1997.

Raines, G. L. and B. R. Johnson. Digital representation of the Washington state geologic map: A contribution to the Interior Columbia River Basin Ecosystem Management Project. Open File Report 95-684, U. S. Geological Survey, 1996.

Reid, I., J.C. Bathurst, P.A. Carling, D.E. Walling, and B.W. Webb, 1997. Sediment erosion, transport, and deposition, in Applied fluvial geomorphology for river engineering and management. Edited by C.R. Thorne, R.D. Hey, and M.D. Newson, pp. 95-135, John Wiley and Sons, Chichester, 1997.

Reid, I., L. Fristick, and L. Layman. 1985. The incidence and nature of bedload transport during flood flows in coarse-grained alluvial channels. Earth Surface Processes and Landforms.

Richards, K. Rivers: Form and process in alluvial channels. Methuen, London, 361 pages, 1982.

Richmond, M. C. and W. A. Perkins. A one-dimensional hydrodynamic and water quality model (MASS1). Pacific Northwest National Laboratory, Richland, WA, 1999.

Richmond, M.C., W.A. Perkins, and C.L. Rakowski. 1999. Two-dimensional analysis of hydraulic conditions and sediment mobility in the lower Snake River for impounded and natural river conditions. Draft report to the U.S. Army Corps of Engineers, Walla Walla District, 1999.

Richmond, M., W. Perkins, and T. Scheibe. 1998. Two-dimensional hydrodynamic, water quality, and fish exposure modeling of the Columbia and Snake Rivers, part 1: Summary and model formulation. Draft final report, Battelle Pacific Northwest Division, PO Box 999, Richland, Washington, 99352. Prepared for the U.S. Army Corps of Engineers, Walla Walla District, under Contract DACW68-96-D-0002.

Rosgen, D. L. Applied river morphology. Wildland Hydrology, Pagosa Springs, CO, 1996.

Rosgen, D. L. A classification of natural rivers. Catena, 22, 169-199, 1994.

Schumm, S. A. The fluvial system. Wiley and Sons, New York, NY, 1977.

Schumm, S. A. River metamorphosis. Journal of the Hydraulics Division, Proceedings of the American Society of Civil Engineers, 95, 255-273, 1969.

Schumm, S. A. A tentative classification of alluvial rivers. U. S. Geological Survey Circular 477, 1963.

Schuster, J. E., C. W. Gulick, S. P. Reidel, K. R. Fecht, and S. Zurenko. Geologic map of Washington: Southeast quadrant. Geologic Map GM-45, Washington State Department of Natural Resources, Division of Geology and Earth Resources, Olympia, WA, 1997.

Stanford, J. A., J. V. Ward, W. J. Liss, C. A. Frissell, R. N. Williams, J. A. Lichatowich, and C. C. Coutant. A general protocol for restoration of regulated rivers. Regulated Rivers: Research and Management, 12, 391-413, 1996.

Thorne, C. R. Channel types and morphological classification, in Applied fluvial geomorphology for river engineering and management, edited by C. R. Thorne, R. D. Hey, and M. D. Newson, pp. 175-222, John Wiley and Sons, Chichester, 1997.

USFWS. 1999. Fish and wildlife coordination act report for the lower Snake River juvenile salmon migration feasibility study. Technical report, U.S. Fish and Wildlife Service, Upper Columbia River Basin Office, Columbia River Fisheries Program Office, and Idaho Fishery Resource Office.

Vanoni, V. Sedimentation engineering. ASCE Manual 54, American Society of Civil Engineers, New York, NY, 1975.

Williams, G.P. 1978. Bank-full discharge of rivers, in Water Resources Research, 14(6), 1141-1154, 1978.

12. Glossary

Alluvial river: A river whose bed and banks are adjustable by current fluvial processes.

Armoring: The process of progressive coarsening of the bed layer by removal of fine particles until the bed becomes resistant to scour.

Bankfull channel: The terminus of the actively used channel and beginning of floodplain in an alluvial river.

Bankfull discharge: The discharge corresponding to the bankfull channel.

Bed load: Material moving on or near the river bed by rolling, sliding, or jumping (saltation). Bed load particles are in constant or frequent contact with the river bed.

Boundary conditions: Definition or statement of conditions or phenomena at the boundaries of an area being modeled; e.g., water surface elevations, flows, sediment concentrations, etc.

Boundary roughness: The roughness of the bed and banks of a river.

Boundary shear stress: Force per unit area exerted on the channel bed by a given flow; largely responsible for mobilizing the bed surface and transporting sediment.

Channel morphology: The shape, size, form, and particle size of a channel created by the interaction of fluvial, biological, and geomorphic processes.

Colluvial river: A river whose bed and banks are comprised of material deposited by forces other than its current flow regime (e.g., mass wasting, glacial deposits).

Critical shear stress: The shear stress (frictional force per unit area) at which bed particles are just able to move, and entrainment is initiated.

Cross section: A profile across a river channel perpendicular to the direction of water flow.

Fluvial processes: Processes associated with the work of streams and rivers in the shaping of landforms.

Geomorphic: Of or resembling the earth, its shape, or surface configuration.

Hydraulic geometry: The relationship of channel width, depth, velocity, and cross-sectional area as a function of discharge.

Hydrodynamic model: The mathematical computation of hydraulic characteristics (e.g., depth (water surface elevation), velocity, slope) of a river as a function of discharge.

Lithology: The gross physical character of a rock or rock formation.

Physiography: Features of the earth's surface, including topography, elevation, aspect, slope, and climate.

Planform: The shape, size, and dimensions of a channel and overbank features as viewed from directly above.

Redd: A fish nest constructed for containing eggs, usually referring to one constructed by a salmon or trout.

Steady state model: Model in which the variables being investigated do not change with time.

Thalweg: An imaginary longitudinal line corresponding to the deepest part of a river channel; usually estimated from a continuous series of cross sections along a river

T: Stream power per unit bed area

Annex A
The 10 Percent Exceedance-flows

ANNEX A
THE 10 PERCENT EXCEEDANCE-FLOWS

The figures in this section are organized as follows:

- Reach scale maps of simulated velocity distribution for each existing pool, starting upstream near the confluence with the Clearwater River. The impounded river map is Figure A-1. The unimpounded river map is Figure A-2.
- A large-scale velocity comparison map for the 10 percent exceedance-flow near the Lower Granite Dam is shown in Figure A-3.
- Large-scale 10 percent exceedance-flow velocities for the unimpounded river and historic observations of dominant substrate size are shown in Figure A-4.
- The full set of figures for the entire lower Snake River can be viewed electronically on the Walla Walla District home page (http://www.nww.usace.army.mil).

This page is intentionally left blank.

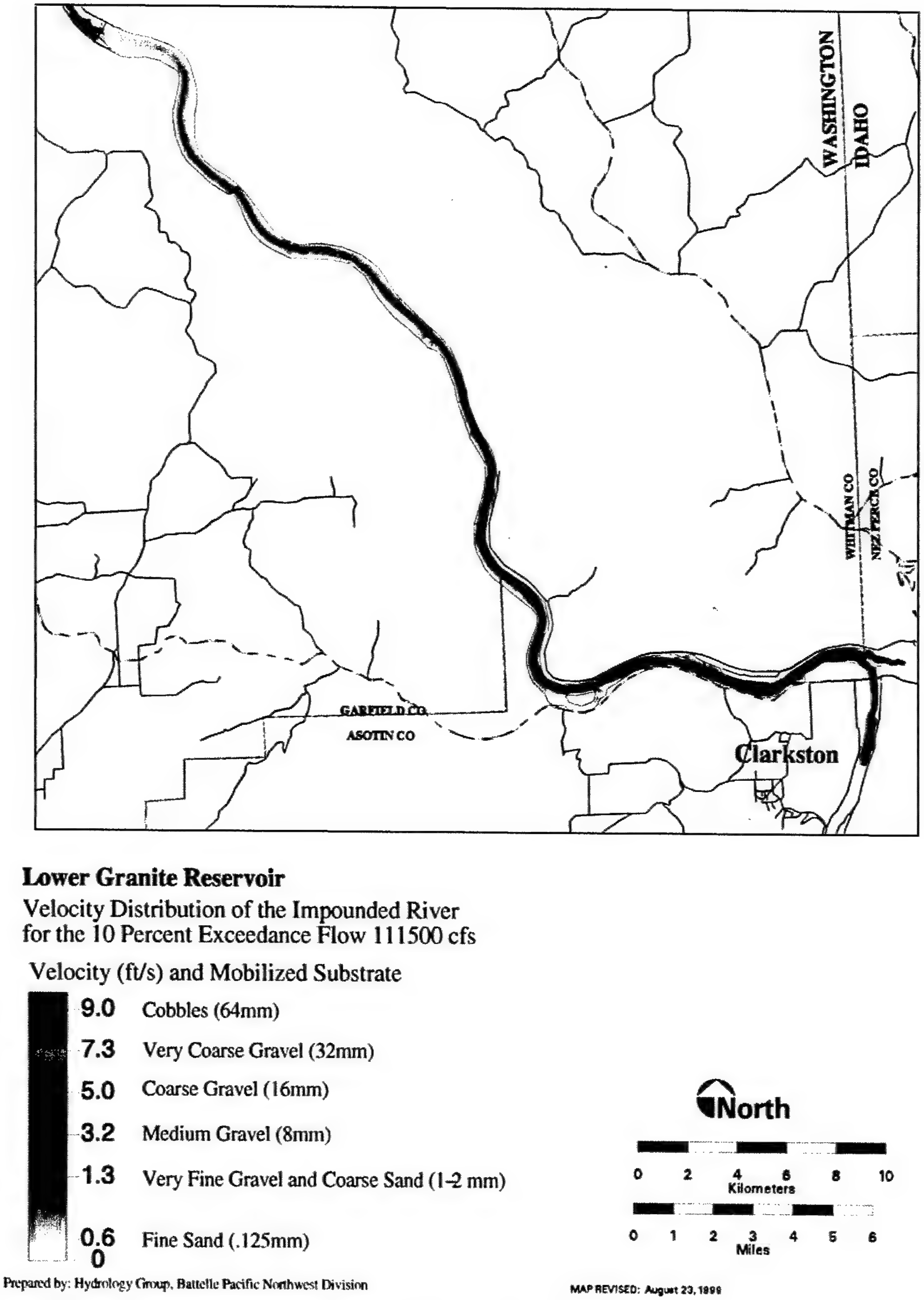


Figure A-1. Modeled 10 Percent Exceedance-flow Velocity Distribution for the Lower Granite Reservoir

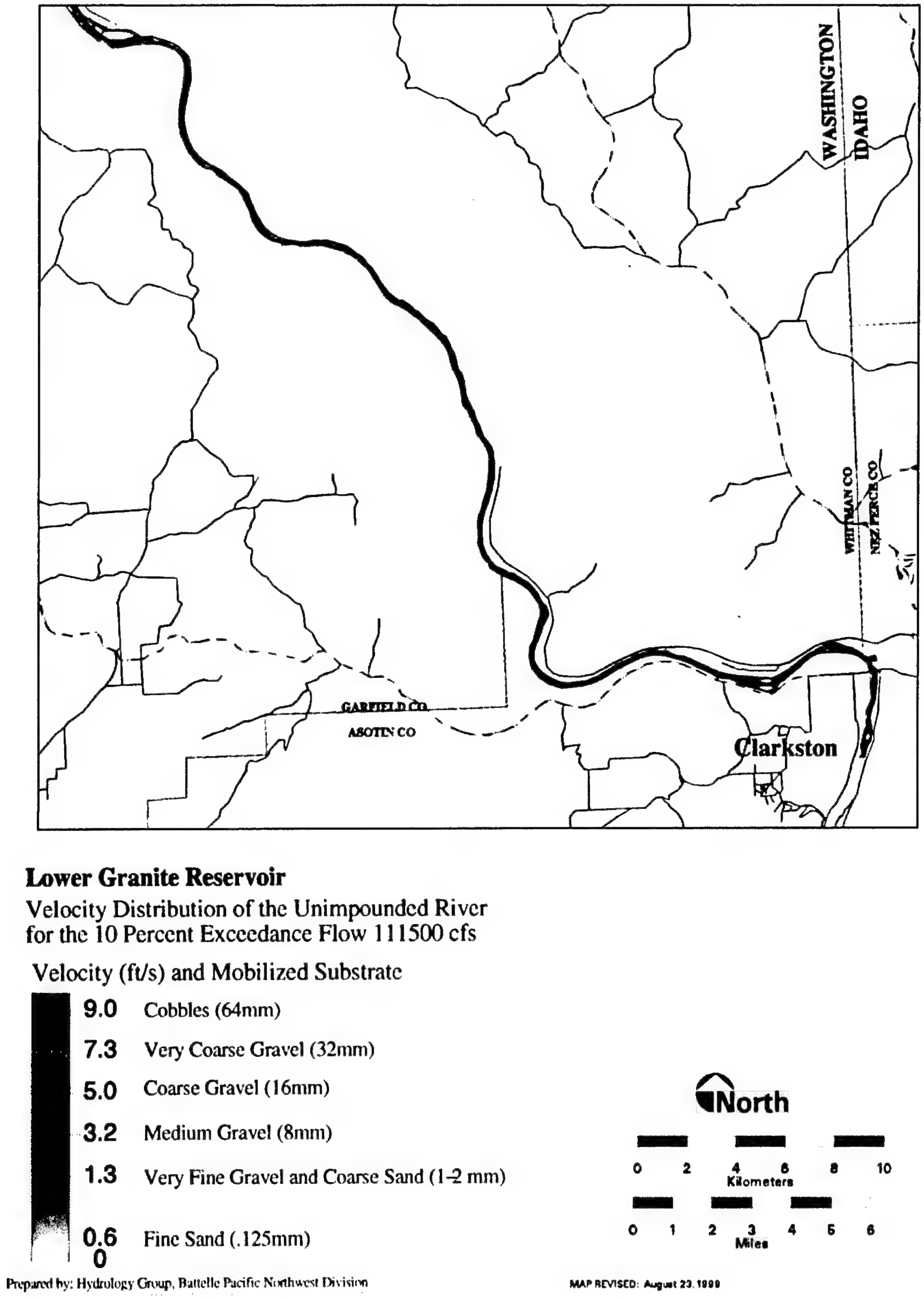


Figure A-2. Modeled Unimpounded River 10 Percent Exceedance-flow Velocity Distribution for the Lower Granite Reservoir

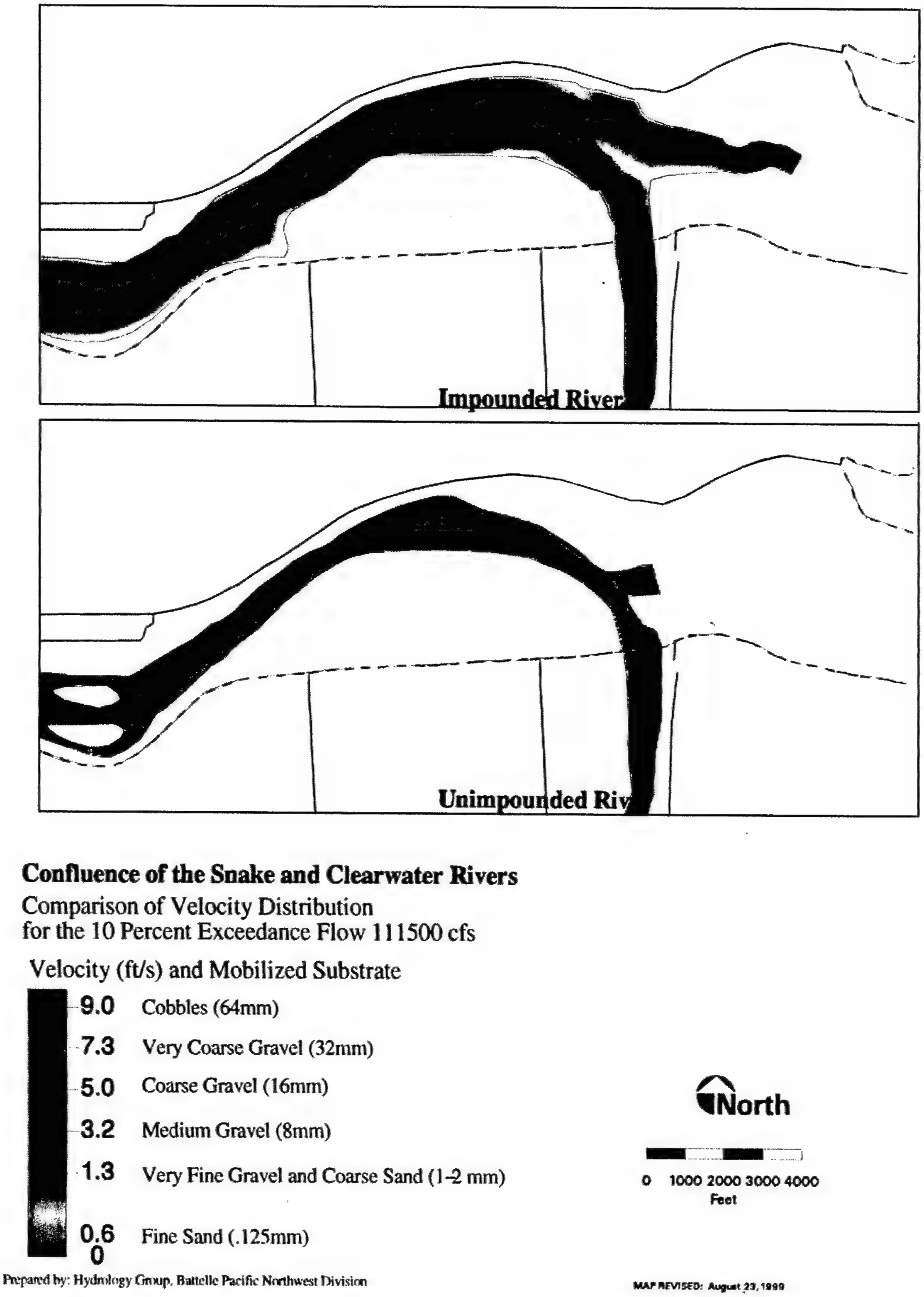


Figure A-3. Comparison of the 10 Percent Exceedance-flow Velocity Distribution near the Confluence of the Snake and Clearwater Rivers for the Full-pool and Unimpounded River

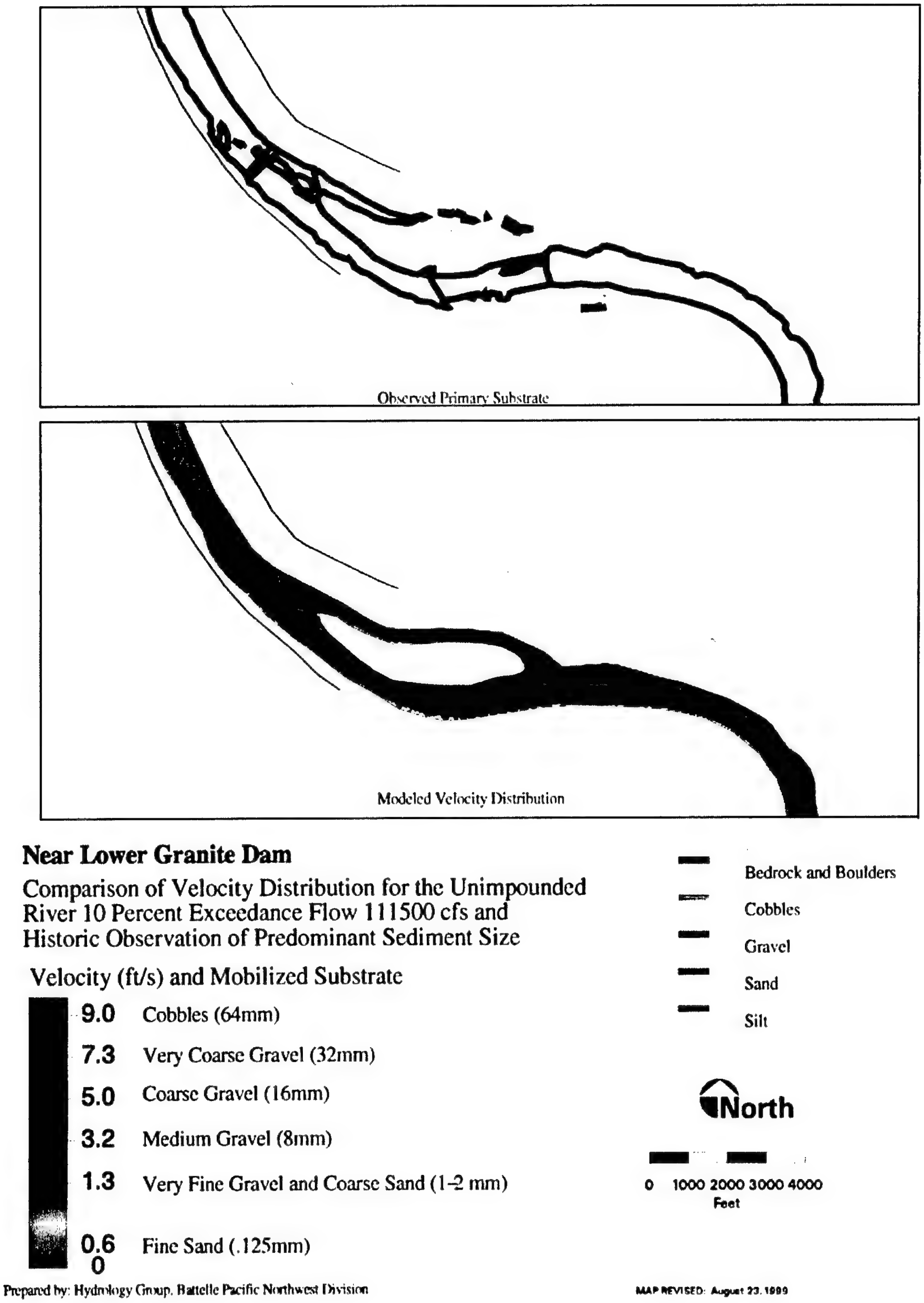


Figure A-4. Comparison of the 10 Percent Exceedance-flow Velocity Distribution and Historic Dominant Substrate near Lower Granite Dam for the Unimpounded River Simulations

Annex B

The 50 Percent Exceedance-flows

ANNEX B
THE 50 PERCENT EXCEEDANCE-FLOWS

The figures in this section are organized as follows:

- Reach scale maps of simulated velocity distribution for each existing pool, beginning upstream near the confluence with the Clearwater River. The impounded river map is Figure B-1, followed by the unimpounded river map, Figure B-2.
- A large-scale velocity comparison map for the 50 percent exceedance-flow near the Lower Granite Dam is shown in Figure B-3.
- A potential spawning habitat suitability map for the 50 percent exceedance-flow near the confluence of the Snake and Clearwater Rivers is shown in Figure B-4.
- A potential rearing habitat suitability maps for the 50 percent exceedance-flow near the confluence of the Snake and Clearwater Rivers is shown in Figure B-5.

- The full set of figures for the entire lower Snake River can be viewed electronically on the Walla Walla District home page (http://www.nww.usace.army.mil).

This page is intentionally left blank.

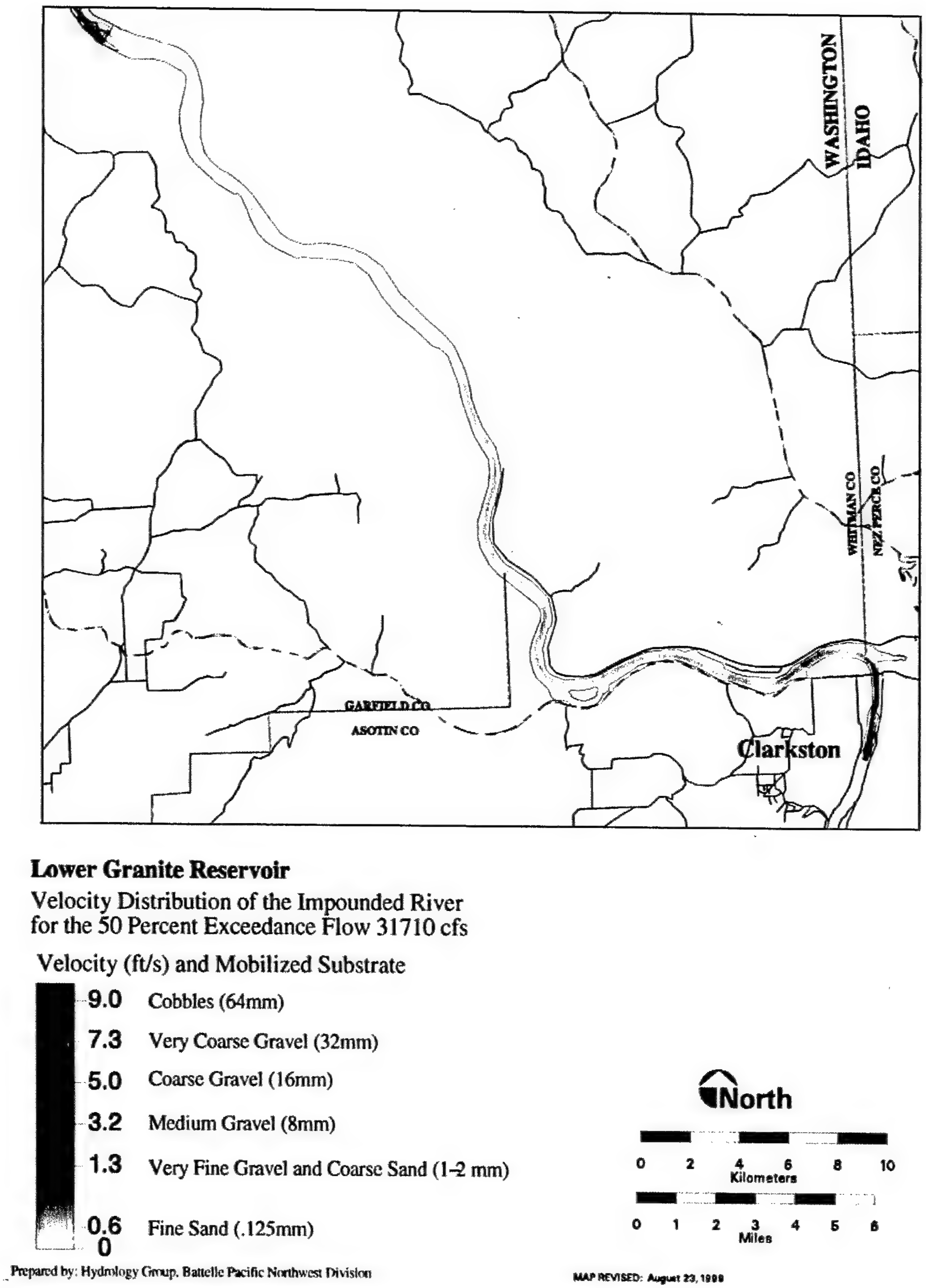
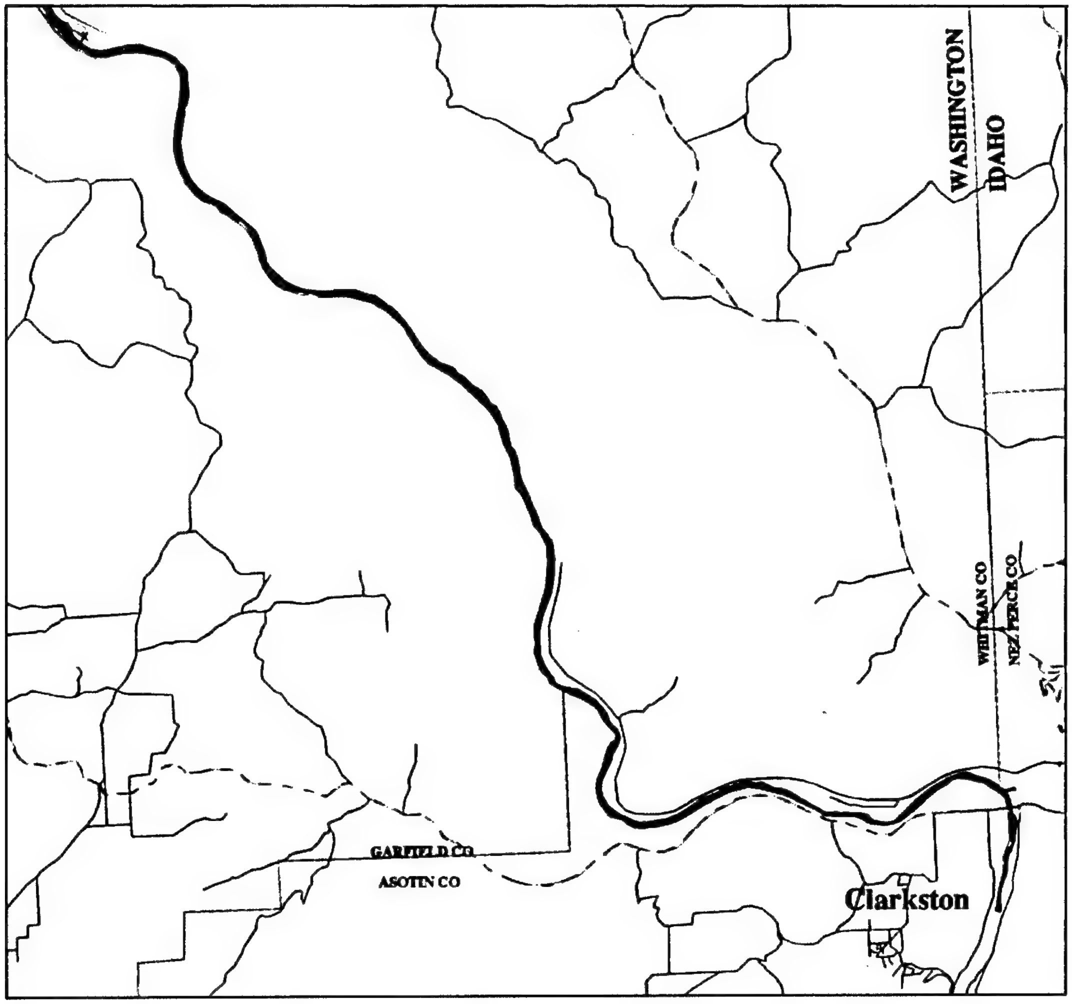


Figure B-1. Modeled 50 Percent Exceedance-flow Velocity Distribution for the Lower Granite Reservoir



Lower Granite Reservoir

Velocity Distribution of the Unimpounded River
for the 50 Percent Exceedance Flow 31710 cfs

Velocity (ft/s) and Mobilized Substrate

9.0 Cobbles (64mm)

7.3 Very Coarse Gravel (32mm)

5.0 Coarse Gravel (16mm)

3.2 Medium Gravel (8mm)

1.3 Very Fine Gravel and Coarse Sand (1-2 mm)

0.6 Fine Sand (.125mm)

0

North

0 2 4 6 8 10
Kilometers

0 1 2 3 4 5 6
Miles

Prepared by: Hydrology Group, Battelle Pacific Northwest Division

MAP REVISED: August 23, 1999

Figure B-2. Modeled 50 Percent Exceedance-flow Velocity Distribution for the Lower Granite Reservoir for the Unimpounded River

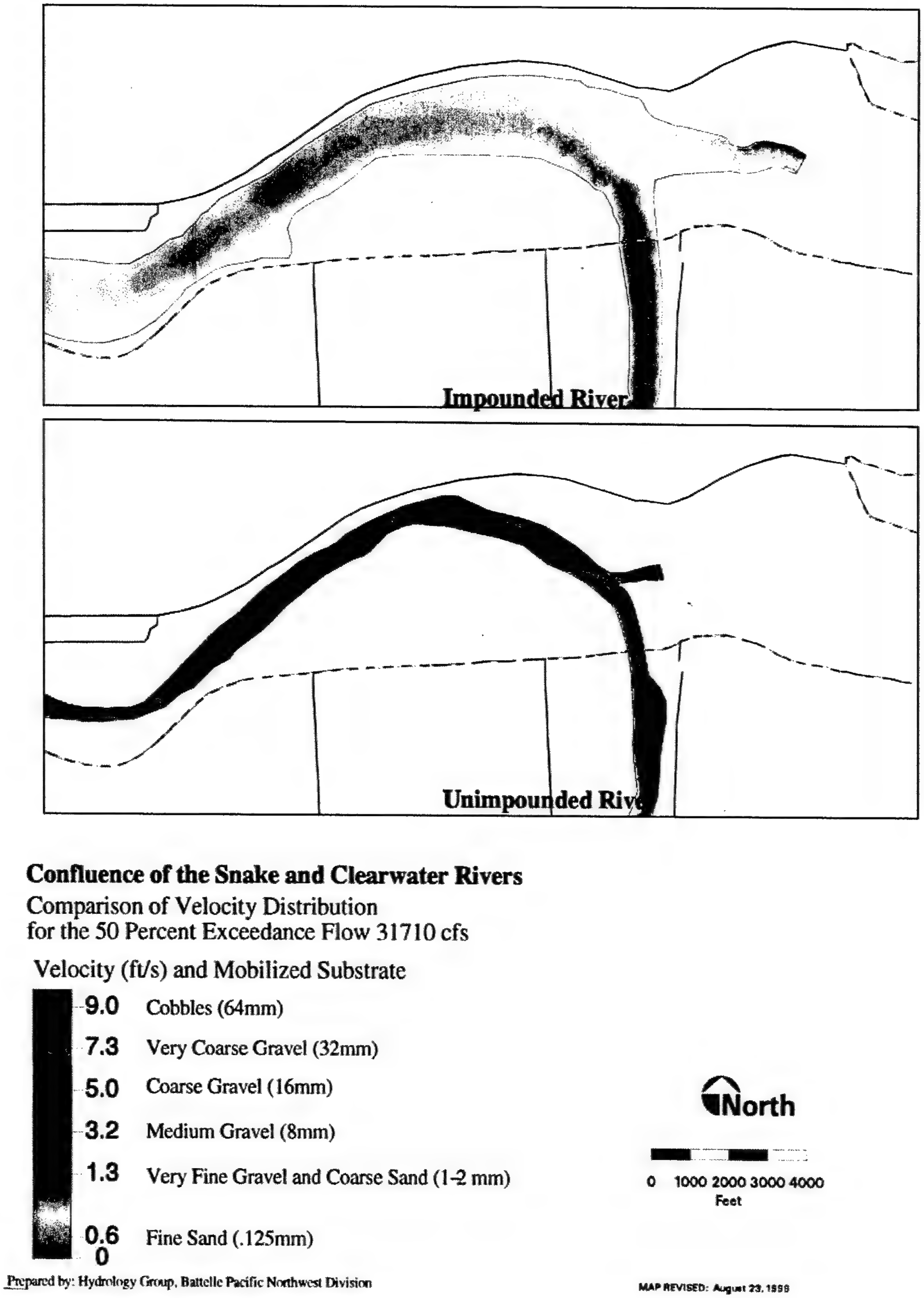
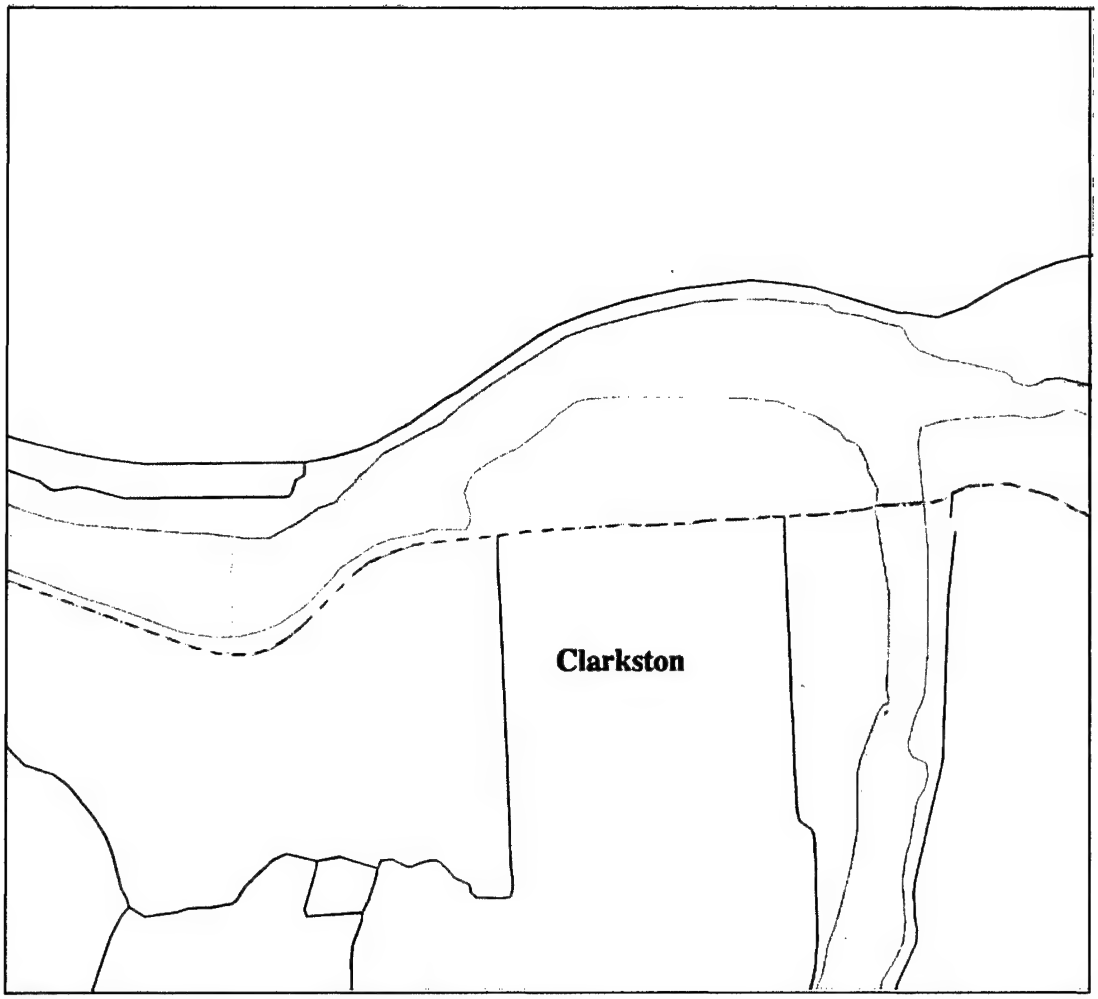


Figure B-3. Comparison of the 50 Percent Exceedance-flow Velocity Distribution near the Confluence of the Snake and Clearwater Rivers for the Full-pool and Unimpounded River



Confluence of the Snake and Clearwater Rivers

Fall Chinook Spawning Habitat Suitability for the Impounded River
for the 50 Percent Exceedance Flow 31710 cfs

Unsuitable Habitat

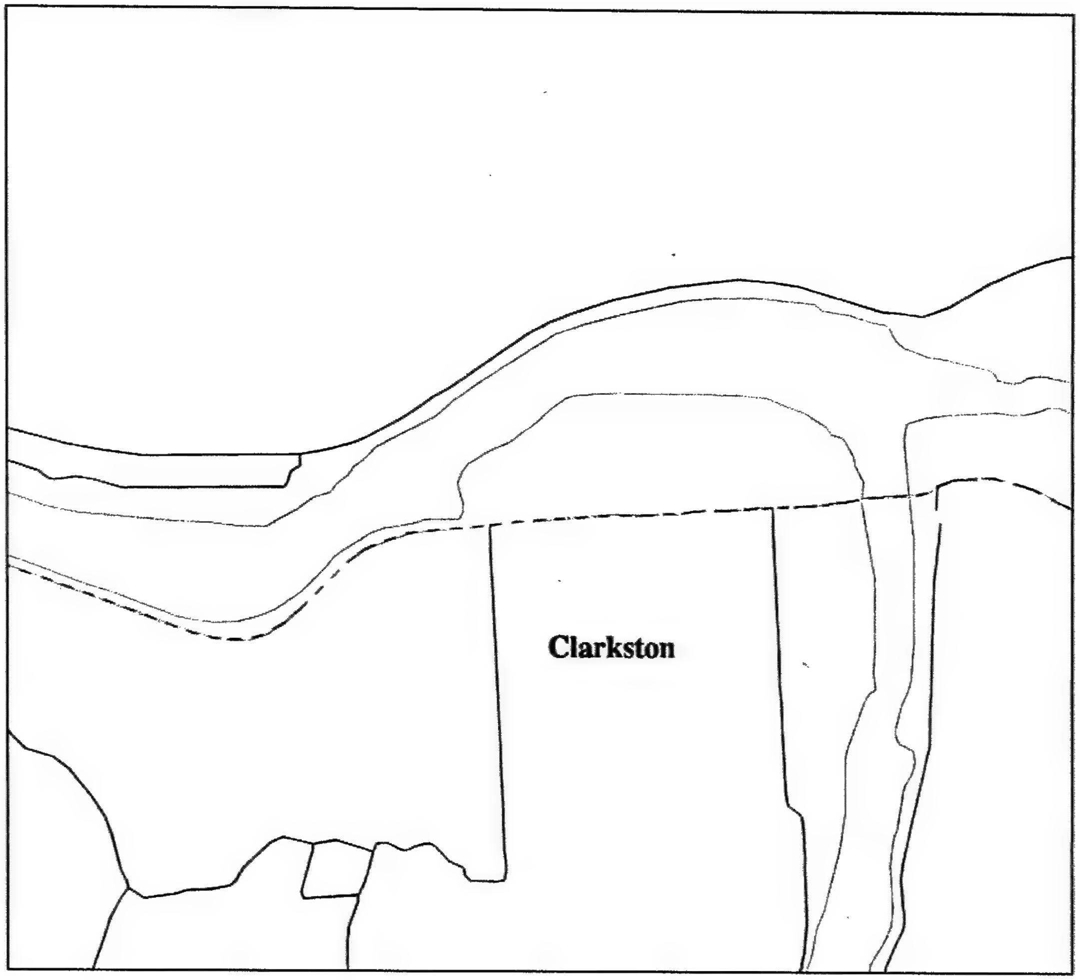
Unknown (Velocity and Depth Criteria met, but Substrate Unknown)

Suitable Habitat

North

0 1000 2000 3000 4000
Feet

Figure B-4. Potential Habitat Suitability for Fall Chinook Spawning Habitats near the Confluence of the Clearwater and Snake Rivers for the Impounded River



Confluence of the Snake and Clearwater Rivers
Fall Chinook Rearing Habitat Suitability for the Unimpounded River
for the 50 Percent Exceedance Flow 31710 cfs

Unsuitable Habitat

Suitable Habitat

North

0 1000 2000 3000 4000
Feet

Figure B-5. Potential Habitat Suitability for Fall Chinook Rearing Habitats near the Confluence of the Clearwater and Snake Rivers for the Unimpounded River

This page is intentionally left blank

Annex C

The 80 Percent Exceedance-flows

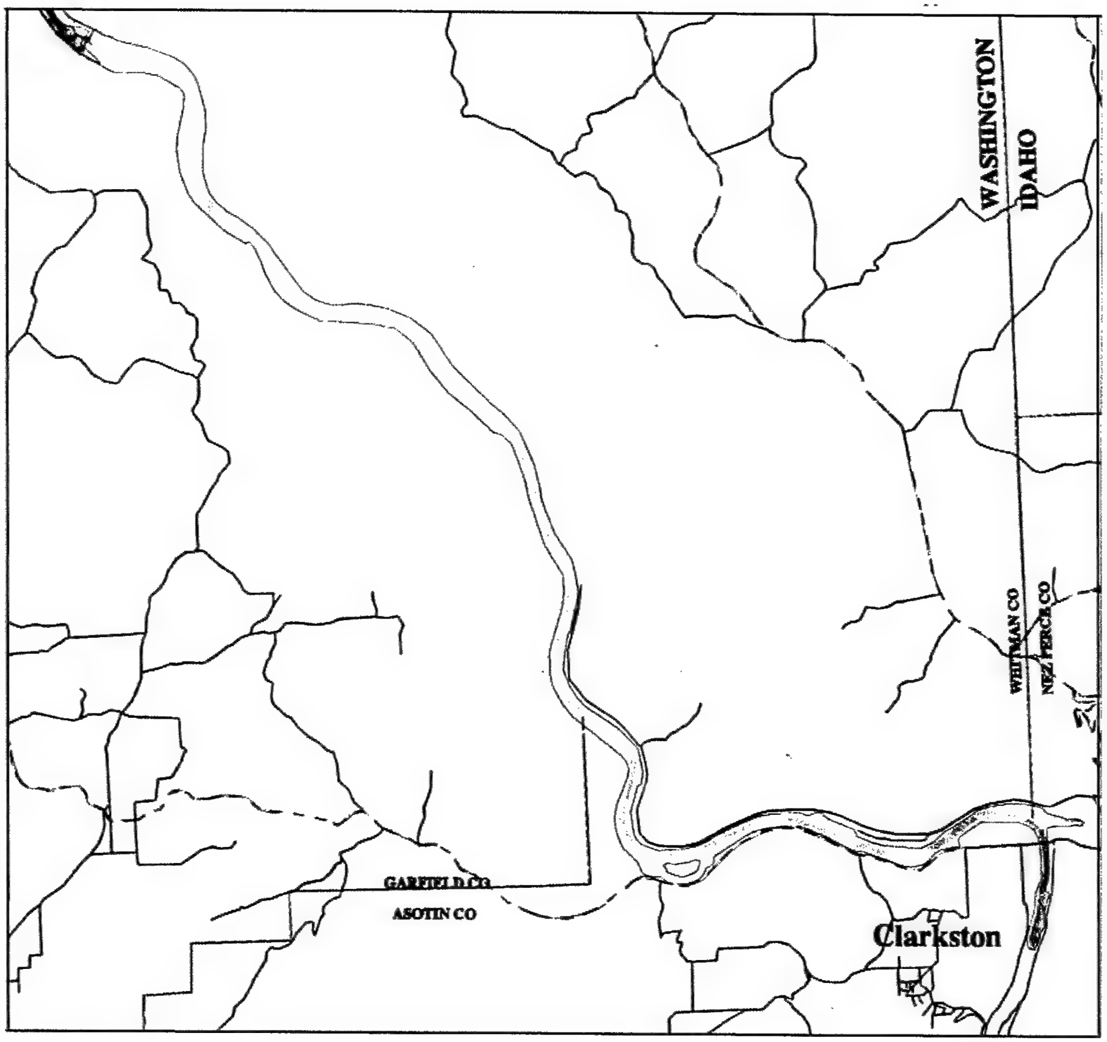
ANNEX C
THE 80 PERCENT EXCEEDANCE-FLOWS

The figures in this section are organized as follows:

- Reach scale maps of simulated velocity distribution for each existing pool, beginning upstream near the confluence with the Clearwater River. The impounded river map is Figure C-1, followed by the unimpounded river map (Figure C-2).
- Large-scale velocity comparison maps for the 80 percent exceedance-flow near the confluence of the Snake and Clearwater Rivers are shown in Figure C-3.

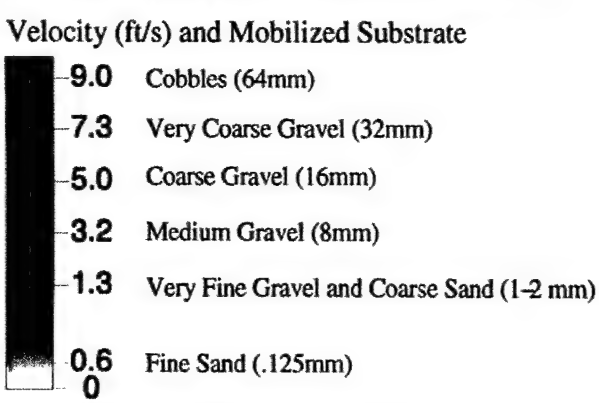
- The full set of figures for the entire lower Snake River can be viewed electronically on the Walla Walla District home page (http://www.nww.usace.army.mil).

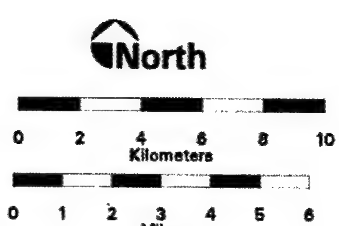
This page is intentionally left blank.



Lower Granite Reservoir

Velocity Distribution of the Impounded River
for the 80 Percent Exceedance Flow 19900 cfs





Prepared by: Hydrology Group, Battelle Pacific Northwest Division

MAP REVISED: August 23, 1999

Figure C-1. Modeled 80 Percent Exceedance-flow Velocity Distribution for the Lower Granite Reservoir

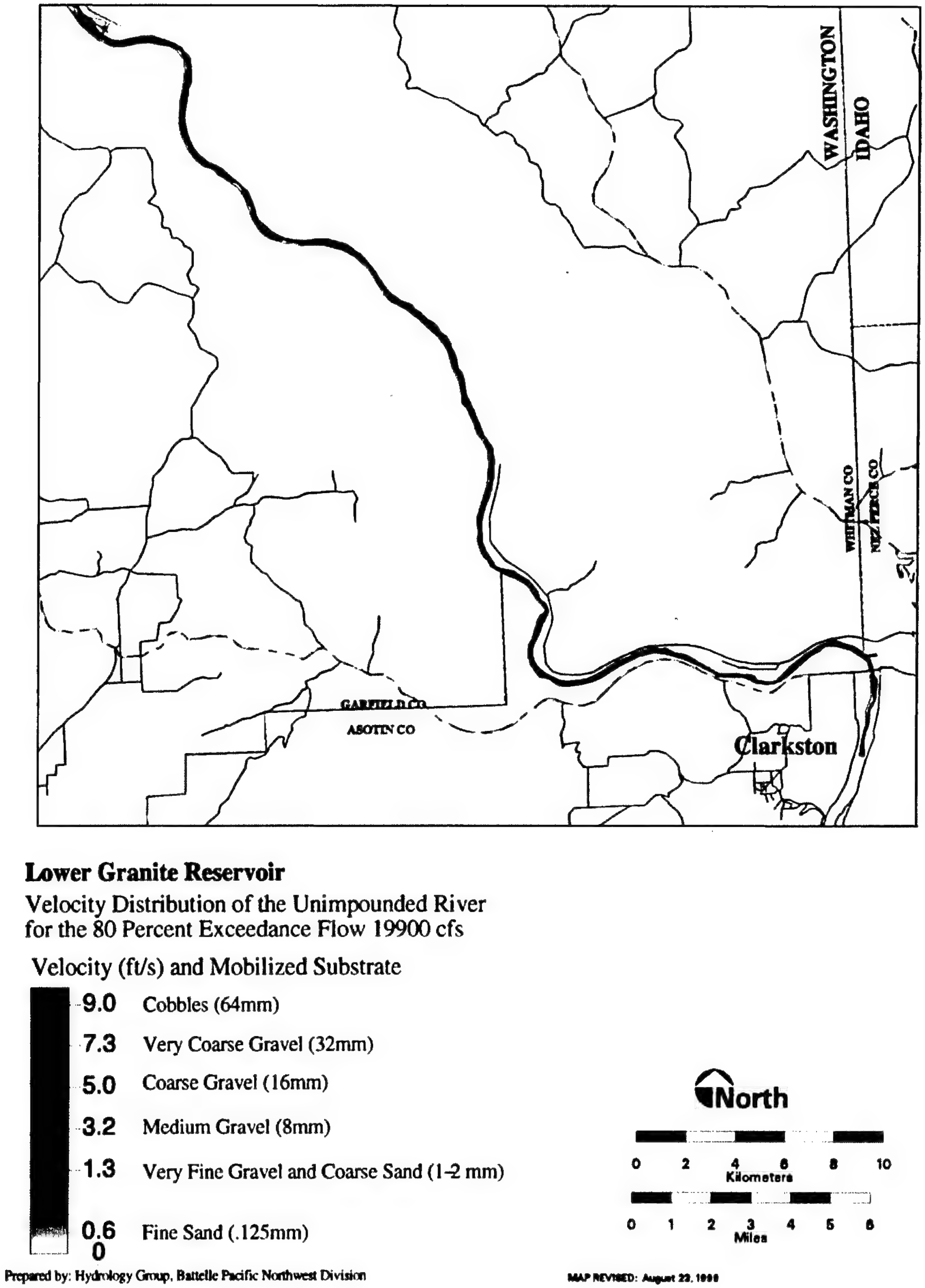


Figure C-2. Modeled 80 Percent Exceedance-flow Velocity Distribution near the Lower Granite Reservoir for the Unimpounded River

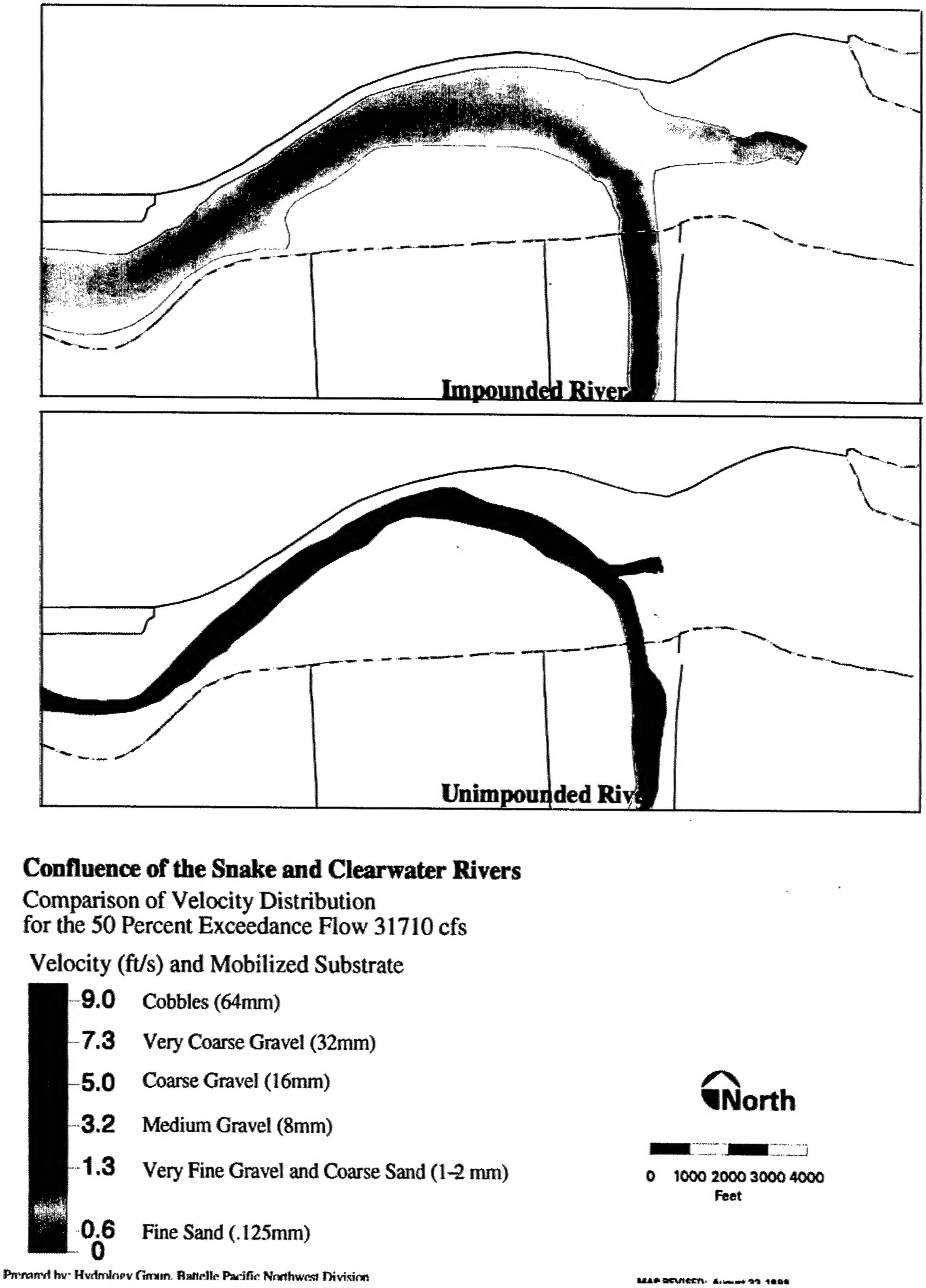


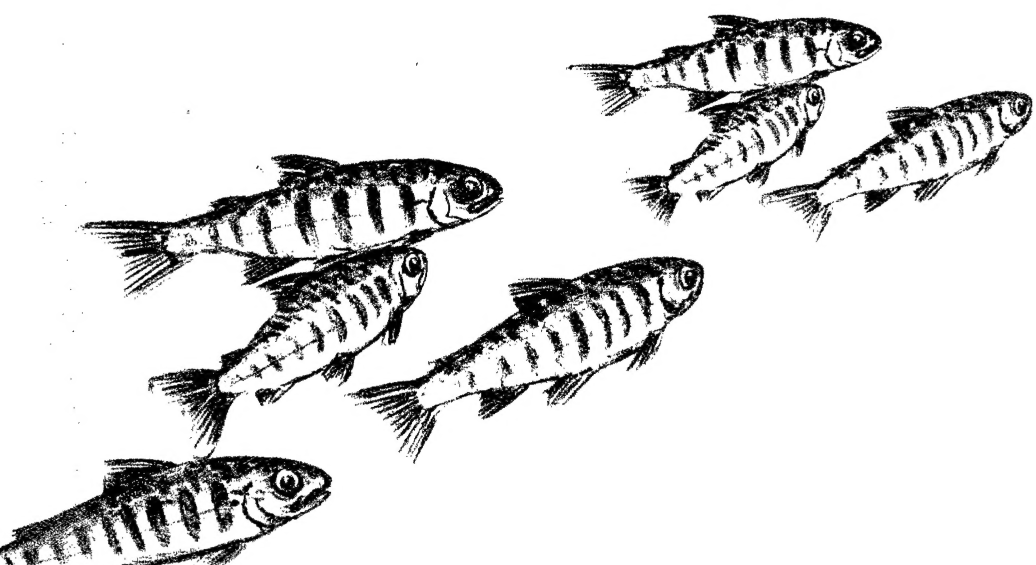
Figure C-3. Comparison of the 80 Percent Exceedance-flow Velocity Distribution near the Confluence of the Snake and Clearwater Rivers

This page is intentionally left blank

For More Information

Visit the Walla Walla District Home Page
at http://www.nww.usace.army.mil

Department of the Army
Walla Walla District, Corps of Engineers
201 North Third Avenue
Walla Walla, WA 99362-1876



EPA

Bonneville
Power Administration